Zero-Liquid Discharge System at Duke Energy Mayo Plant

Dr. Matthias Loewenberg, GEA Process Engineering Inc., Columbia MD

Danny Johnson PE, Duke Energy, Raleigh NC

John Edelen PE, Duke Energy, Raleigh NC

IWC12-16

Keywords: Mayo Plant, Zero Liquid Discharge, Falling Film Evaporator, Brine Concentrator, Mechanical Vapor Recompression, Forced Circulation Evaporator, Brine Cooler, Boron Scrubber, Water Reuse, Fly Ash Mixing, Redundant System, NPDES Permit.

ABSTRACT

Duke Energy is currently installing a Zero-Liquid Discharge treatment system, provided by GEA Processing Engineering Inc., for Flue Gas Desulfurization Wastewater at their Mayo Plant, located near Roxboro NC. The paper outlines the various concepts which were considered as well the selected solution that is currently in the engineering phase of the project

Introduction

Duke Energy is currently installing a Zero-Liquid Discharge treatment system for Flue Gas Desulfurization (FGD) Wastewater (Figure 2) at their Mayo Plant located near Roxboro North Carolina. The Mayo Plant started operating in 1983, is located about 60 miles north of Raleigh NC, and has a generation capacity of 742MW.

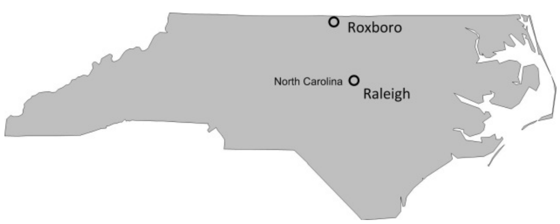

Figure 1: Mayo Plant is located approximately 60 miles north of Raleigh NC

The system, designed and supplied by GEA Process Engineering Inc., supports Duke Energy's commitment to provide safe, reliable and environmental friendly energy generation. The Zero-Liquid Discharge addition to their existing FGD scrubber supports compliance with tight National Pollutant Discharge Elimination System (NPDES) wastewater discharge regulations.

The project is completing the engineering phase and beginning the construction contracting effort. It is scheduled to be operational by the end of 2013.

This paper outlines the methodology behind the selection of the Partial Zero-Liquid Discharge approach to support environmental compliance.

Background

With the addition of a wet FGD system at the Mayo Plant, new discharge limits were imposed in the site's renewal of the NPDES permit in 2008. To meet discharge limits for selenium and mercury, a gypsum settling pond and bioreactor were installed to treat FGD wastewater. The Mayo Plant treated wastewater discharges to the low turnover Mayo Lake. Water quality monitoring since the FGD went into service showed an increasing concentration of several constituents in the Mayo Lake. Since the Plant's outfall consists of different wastewater

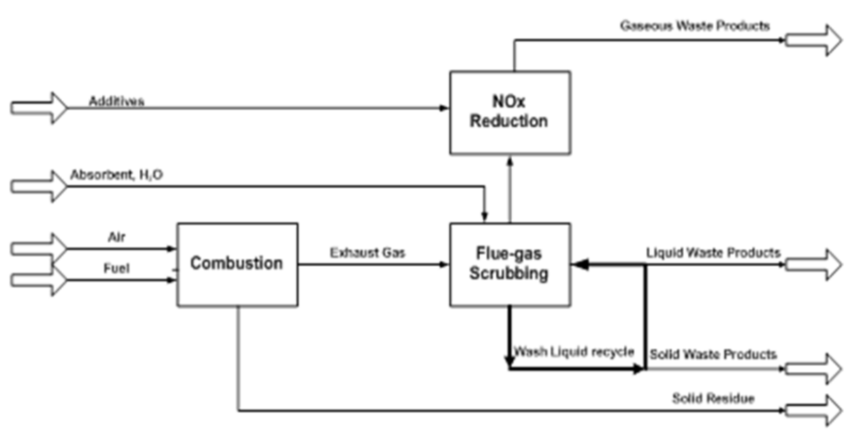

Figure 2: Simplified Plant overview for FGD Waste Water source (Liquid Waste Products)

sources, a metal loading study was performed to identify the source and to quantify the impact of different constituents on the lake. The study identified the key contaminants of concern as aluminum, boron, copper, manganese, selenium, silver, and thallium. Chloride concentration in the lake was also shown to be trending upwards. Although the concentration was below the permit limits, there were operational concerns with the elevated levels of chlorides.

Several treatment options were considered for the facility to support compliance with the permit limits.

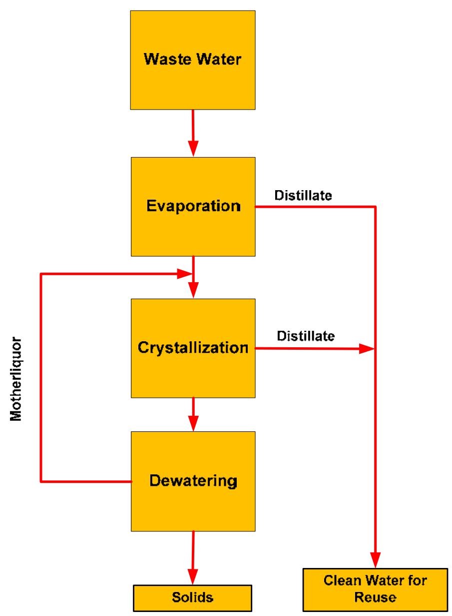

Figure 3: Traditional Zero-Liquid Discharge

Based on a high level evaluation, the following three options were further examined in more detail:

- Pipe wastewater to a nearby river
- Electrocoagulation
- Zero-Liquid Discharge, traditional and partial

Traditional Zero-Liquid Discharge (see Figure 3) evaporates and concentrates either raw or pretreated FGD wastewater past its crystallization point which results in a recovered water stream and salt. The Partial Zero-Liquid Discharge (see Figure 4) concentrates the wastewater and reduces its volume significantly such that the remaining liquid can be solidified with binders like cement or fly ash.

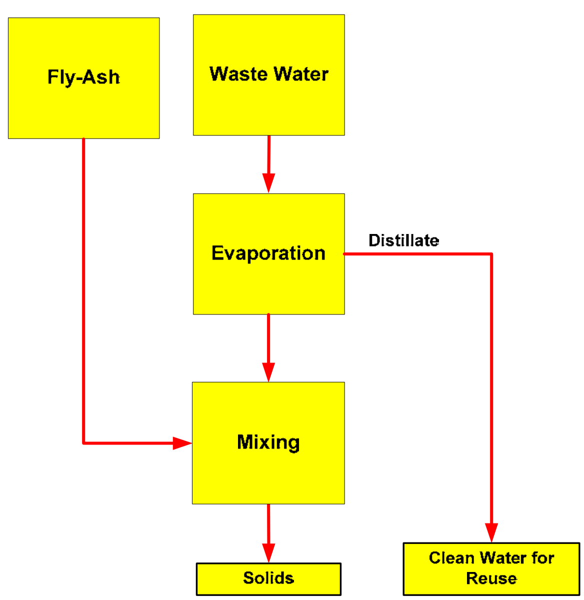

Figure 4: Partial Zero-Liquid Discharge

The evaluation considered the impact of changes in fuel sources, life cycle costs, as well as the anticipated future regulatory environment.

The study concluded that a Zero-Liquid Discharge approach is preferred for Mayo Plant’s needs based on an evaluation criteria that included multi-pollutant removal ability, demonstrated technology, time constraints, and life cycle cost.

ZLD Detailed Study Overview

To further detail the scope of the Zero-Liquid Discharge solution, a subsequent study was performed considering a typical and estimated maximum water analysis for the FGD blowdown.

Three ZLD alternatives were considered, two traditional and one partial ZLD solution. The traditional ZLD options included one with softening pretreatment followed by an evaporator with a high temperature crystallization, and one with an evaporator using low temperature crystallization process.

Table 1: Evaluated ZLD Alternatives

	Alternative		
	1	2	3
Softening		•	
Evaporation	•	•	•
Low Temperature Crystallization			•
High Temperature Crystallization	•	•	
Fly Ash Mixing	•		

The chloride content of the ZLD feedwater is dependent on the chlorides in the coal and the FGD scrubber blowdown concentration. A total of 9 flow versus inlet chloride scenarios were considered for each alternative. These scenarios allowed for a range of equipment configurations to provide the plant high operational reliability and flexibility.

A caustic vapor scrubber for the reduction of boron and droplets from the vapor stream was included for all alternatives to ensure a clean distillate stream for use within the plant.

Selected ZLD Solution for Mayo Plant

Based on the data provided by the detailed study and a comparison of alternatives, Duke Energy selected the Partial Zero-Liquid Discharge solution as most appropriate.

The Partial Zero-Liquid Discharge system consists of falling film evaporator technology (Primary Evaporator [PE]) for total of 370 GPM feed with a forced circulation evaporator (Secondary Evaporator [SE]) in order to reduce the FGD blowdown volume significantly. A following Brine Cooler [BC] decreases the brine temperature prior to storage. The resulting concentrated brine will be mixed with Mayo Plant fly ash and disposed in a new on-site landfill with leachate control. The distillate water will be used in the Plant systems, reducing the make-up water demand.

As outlined in Figure 5, three parallel trains of Primary Evaporators with feed of 150 GPM each (3x40%) FGD blow-down as well as two 100% Secondary Evaporators are utilized. A brine cooler system reduces the brine temperature for easier handling as well as to lower cost materials of the brine system.

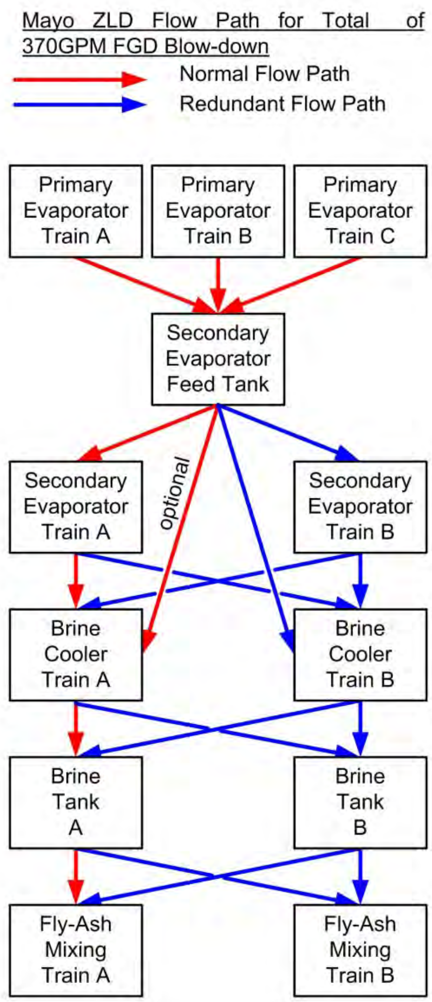

Figure 5: Mayo ZLD-System Process Flow Diagram

A maximum discharge of 18 GPM of brine is set as the objective, which is balanced based on the estimated amount of fly-ash for mixing.

The design provides redundancy in the form of parallel operating trains or system in back-up configuration to minimize the risk of down time of the ZLD system.

ZLD-System Components

The three major parts of the ZLD System (Primary Evaporator, Secondary Evaporator and Brine Cooler) are discussed in more detail below.

Primary Evaporator

The Primary Evaporator is used for the majority of the concentration (Concentration Factor ~8-12). The PE is a falling film type evaporator with a mechanical vapor compression system, outlined in Figure 6. Due to the nature of FGD blowdown the system is operated as a seed system.

To improve the evaporation system, various GEA in-house evaporation pilot tests with actual Mayo FGD blowdown were performed. These were to quantify boron content in the vapor stream and to optimize the vapor scrubber to remove the boron from the water vapor stream.

The FGD blowdown is currently discharged from the scrubber to a settling pond. From here the blowdown is fed to a bioreactor. The bioreactor will be decommissioned once the ZLD system becomes operational. The Gypsum Settling Pond will remain and acts as a large holding tank (~30 days holding capacity), which provides the ZLD System with a steady feed and storage capacity.

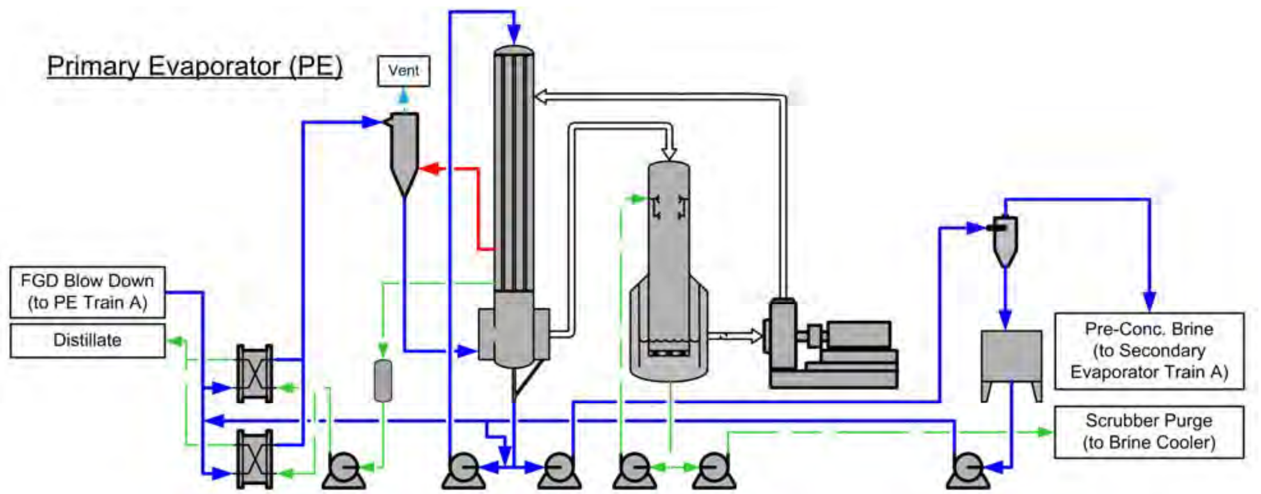

Figure 6: One of Three Primary Evaporator, Falling Film Type Evaporator with Mechanical Vapor Compression

The FGD wastewater is introduced into one of two 100% plate heat exchangers per PE to preheat the wastewater against the hot distillate from the falling film evaporator. Calcium sulfate, one of the main scaling components, is inversely soluble with temperature which means that the solubility decreases with increase in temperature. In addition, the blow-down itself is already saturated with calcium sulfate from the scrubber operation. Because both aspects have an undesirable impact on the scaling within the plate heat exchanger, seed crystal is added prior to the heat exchanger to help mitigate scaling. Also, a redundant heat exchanger is installed having one unit operational and the second either in stand-by or available for cleaning.

The preheated wastewater is additionally heated by the vent stream from the falling film evaporator shell side to further optimize the energy consumption of the system. This preheating takes place in a two-stage flash system called a deaerator. While in the upper chamber steam is partially condensed into the wastewater, the lower chamber flashes off a fraction of water again. This flashing action removes inert gases and therefore deaerates the wastewater. Releasing inert gases has two main purposes; on one hand it reduces the oxygen level in the water to reduce the corrosion potential in combination with the high concentration of dissolved chlorides and on the other hand it removes inert components before they otherwise would be recompressed in the mechanical vapor recompressor (MVR) and reduces its efficiency.

The wastewater subsequently enters the sump of the falling film evaporator. Here the recirculation pump transfers the liquid to the top tube sheet where the wastewater enters the heat transfer tubes, creating a thin film of cascading water. Inside the tubes the FGD blowdown is concentrated by evaporating water from the solution. Both the water vapor and concentrated wastewater travel down the tubes. At the bottom, the vapor mist is separated from the liquid using centrifugal forces in the vapor-liquid separator which is wrapped around the lower sump area. Concentrated water droplets are then washed down and combined with the wastewater stream in the sump.

Concentrating brine solutions with high concentrations of dissolved chlorides, in most cases result in exotic materials of constructions. While the heat transfer tubes are made of Titanium-Gr.16 the other product wetted materials are made of AL6XN and Hastelloy.

Water vapor leaves the falling film evaporator and is introduced into the vapor scrubber. Boron, as a component of concern with a discharge permit limit, could potentially carry over. Therefore in order to reduce the boron concentration in the distillate (condensed process water vapor) the water vapor is scrubbed.

The scrubbing occurs by an intensive vapor-liquid exchange with a caustic solution. Boron is “captured” in the liquid and therefore removed from the vapor stream. This vapor stream is compressed in a mechanical vapor recompression system. By increasing the pressure of the water vapor, the water vapor can be condensed at a higher saturated temperature and consequently used as the heating medium within the evaporation process. The resulting distillate is used for preheating the incoming FGD blowdown.

During the concentration of the FGD blowdown calcium sulfate will precipitate. In order to reduce the possibility of precipitation on the heat transfer surfaces the Primary Evaporation system is operated in a seed configuration. Precipitation or scaling at the heat transfer surface area would reduce the evaporators’ efficiency and therefore limit the evaporation capacity.

In a seed evaporation system, the predominate crystal (seed) in the system is used and artificially introduced into the feed stream. The seed crystals act as nucleation sites for the subsequent calcium sulfate precipitate and crystal growth as the FGD blowdown is concentrated. The seeding process is self-sustaining and after an initial seeding further seed addition is not required.

In order to recover the seed crystals from the concentrated solution, a hydrocyclone is utilized where the overflow is sent to the Secondary Evaporator Feed Tank and the underflow, seed rich fraction, is collected in a Seed Slurry Tank and later combined with the un-concentrated FGD blowdown.

Secondary Evaporator

The concentrated FGD blowdown from the three Primary Evaporator trains will be further concentrated in one of the two Secondary Evaporators, since the primary evaporation step is limited to concentrate the wastewater close to the saturation point of the main salts in the solution, sodium chloride and calcium chloride.

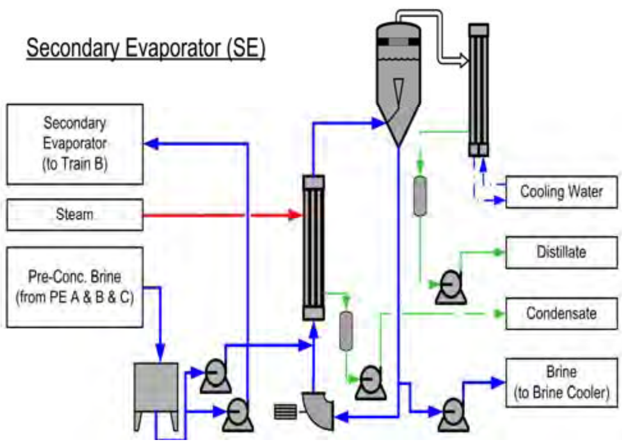

Figure 7: One of Two Secondary Evaporator, Forced Circulation Type Evaporator

For the remaining concentration a successive evaporating step is required to reduce the wastewater volume to match the available fly ash for mixing. Fluctuations in the initial wastewater can result in crystallization at various concentration factors. To successfully manage variations, a forced circulation evaporator system was used, which is typically used for crystallization of salts in the food and chemical industry.

The concentrated wastewater is introduced into the recirculation loop were the temperature is increased in a shell and tube heat exchanger that is heated with plant steam. Boiling in the heat exchanger is suppressed by its elevated pressure. By releasing this pressure to atmospheric conditions in the flash vessel the liquid starts to flash/boil. Since boiling is not occurring on the heat transfer areas, in contrast to the falling film evaporator, the system is able to tolerate precipitation and crystallization much easier. The generated water vapor is subsequently condensed in a shell and tube condenser and combined with the Primary Evaporator distillate for use within the Mayo Plant.

Brine Cooler

Prior to storage of the concentrated wastewater (Brine) in the Brine Tanks the solution is cooled in a Brine Cooler. The solution is cooled to approximately 140°F, which allows the use of less-expensive FRP.

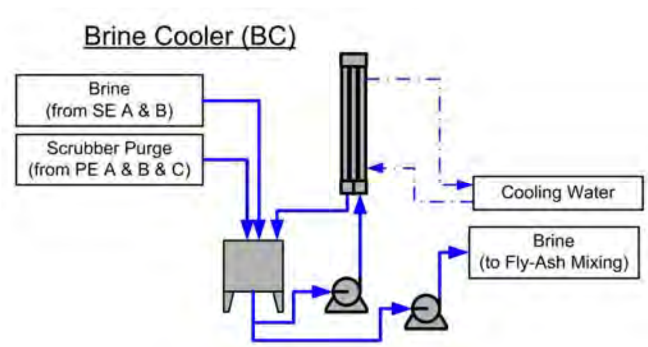

Figure 8: One of Two Brine Cooler, Recirculated Type Cooler

Fly Ash Mixing

The brine is continuously pumped to the two fly ash silos in one of two brine piping recirculation loops (highways). Each brine loop can feed each of two new fly ash mixers. The fly ash and brine mixture is loaded into dump trucks and hauled to a new on-site lined ash storage landfill with a leachate collection and use system.

Summary

The installation of the Zero-Liquid Discharge system at Duke Energy's Mayo Plant is the culmination of site specific situation and constraints, and development of alternative FGD wastewater treatment methods. The capability to remove multiple constituents from the FGD blowdown and recover high quality distillate makes this the solution of choice for the unique conditions at Mayo Plant. Flexibility and redundancy are key requirements to the design and of upmost importance to Duke Energy.

The ZLD project started at the beginning of 2011 and is scheduled to be operational by the end of 2013.

References:

Environmental Protection Agency (2007), Permit NC0038377, December 14

Melches C., Loewenberg M., Hofmann G. (2011), “Concepts in Zero-Liquid Discharge”, International Water Conference, Paper IWC 11-49

Shaw W. (2009), “New Low-Temperature ZLD Process”, International Water Conference, Paper IWC 09-52

Mandigo G. (2009), “ZLD Achieved for Treatment of FGD Waste Water at Iatan Station”, International Water Conference, Paper IWC 09-51