Operating a ZLD, What Does it Take?

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ABSTRACT

Zero Liquid Discharge (ZLD) systems are in use across the United States in the power industry and will continue to be built in plants as discharge permits continue to tighten. The ability to keep a ZLD system operating is critical to keeping plants online and the operational commitments of these systems can be underestimated. This paper describes what is required to successfully maintain operation of different types of ZLD systems. A variety of subjects will be discussed including: system basics, importance of reliability, bare essentials (power, chemicals, and solids removal), and an analysis of manpower requirements.

INTRODUCTION

Several industrial and power generation facilities have been given the opportunity to convert power, chemicals, and manpower into clean water for recycle, while limiting the amount of water discharged to the environment. Defining the actual operating demands of this opportunity, called a Zero Liquid Discharge (ZLD) facility, is not easily quantified. Variation in treatment, operations, and local environment dictate the resources required to implement such a treatment scheme. The costs and energy required to manage these systems can be large enough to require a standalone operations center. When presented with the option of installing a ZLD, considering alternatives to an existing ZLD, or evaluating the impact of possible future regulations, a complete picture should be evaluated for these systems.

While alternative ZLD technologies are being developed and evaluated in many settings, the industry proven technologies include brine concentrators (BC), crystallizers, membrane technologies, and evaporation ponds.

Several membrane technologies have been developed for wastewater reduction and the basis for this paper is the High Efficiency Reverse Osmosis (HERO^{TM}) process.

Evaporation ponds require minimal operating attention and are not discussed in much detail herein.

All ZLD systems require to some extent the following resources:

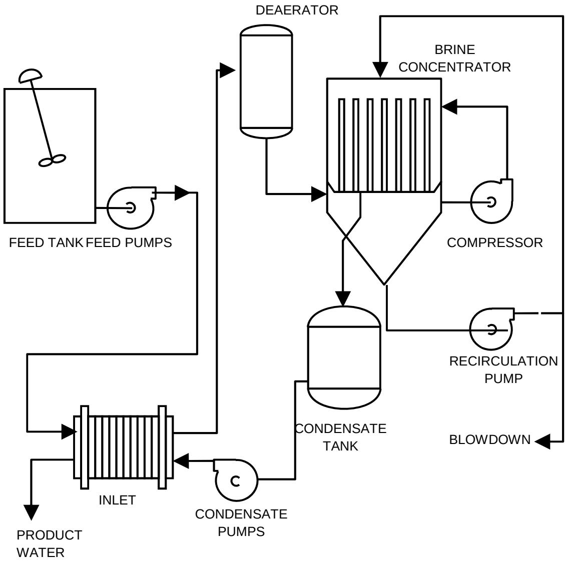
- Power
- Chemicals
- Manpower
- Maintenance

The proceeding pages describe the ZLD systems, provide insight from a plant living with a ZLD as to the importance of proper planning, define the resources required for each alternative technology, and present suggestions on how to minimize resource demands and risk where possible.

ZLD SYSTEMS

BRINE CONCENTRATOR (BC) - Brine concentration refers to the process of partially evaporating water from the waste stream, thereby concentrating the dissolved solids. There are two primary categories of evaporators used in the wastewater treatment industry: thin film and forced circulation. Most brine concentrators in operation are thin film evaporators configured to use a vapor compression, vertical tube evaporation process capable of 90 to 99 percent recovery efficiencies. A simplified schematic of the system is shown in Figure 1.

Figure 1. BC Flow Diagram



An inlet heat exchanger increases the feed temperature to near its atmospheric boiling point by recovering heat from the distillate. Downstream of the exchanger, a deaerator is used to strip the inlet waste stream of corrosive and scale forming constituents. The feed is introduced into the BC sump where it is mixed with concentrated slurry. The sump is continuously recirculated to the top of the evaporator, where it is distributed to the inside wall of a vertical tube heat exchanger as a thin film. Water is evaporated from the film as it passes down the tube.

As the slurry and steam fluid falls back into the BC sump, the steam is pulled through a mist eliminator, is recompressed in the vapor compressor, and sent to the shell side of the vertical heat exchanger. The steam condenses on the outside of the tubes giving up its latent heat of condensation, which causes more water to be evaporated from the brine inside the tubes. The steam condensate is pumped back through the inlet heat exchanger and exits as the brine concentrator product water/distillate. The distillate can be reused at the facility as makeup to a cooling tower or possibly for demineralized water production.

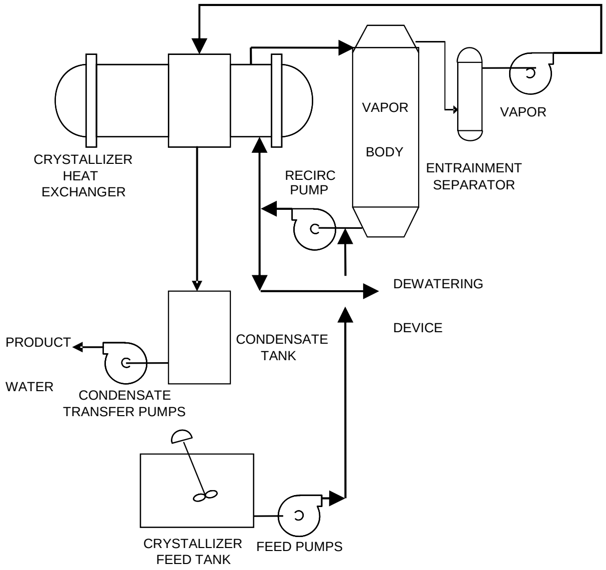
A portion of the recirculated concentrated slurry steam is removed as blowdown to maintain a concentration of dissolved solids. Generally, the blowdown stream cannot be discharged directly and requires a final treatment step such as crystallization or pond disposal.

CRYSTALLIZER - Crystallizers use energy, in the form of a vapor compressor or steam, to increase the salt concentration of highly concentrated water to a concentration where it can be dewatered in a dewatering device such as a centrifuge or sludge press. A simplified schematic of a vapor recompression crystallizer system is shown in Figure 2.

Feed to the crystallizer is sent to the suction of a recirculation pump, where it is mixed with the crystallizer slurry from the crystallizer vapor body. The crystallizer slurry in the vapor body is continuously recirculated through a crystallizer heat exchanger.

The crystallizer heat exchanger is typically a horizontal two-pass, shell and tube, pressurized, condensing type heat exchanger. Crystallizer slurry is circulated on the tube side, and saturated steam from an external source or from the vapor compressor is applied to the shell side.

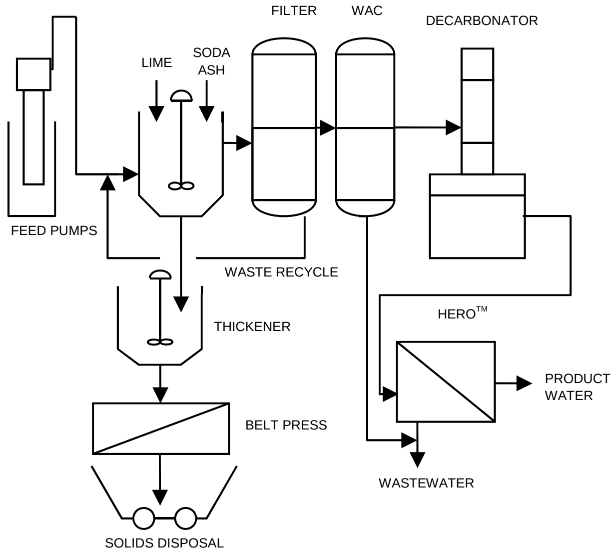
Figure 2. Crystallizer Flow Diagram



The heat of condensation of the steam is used to heat the crystallizer slurry above its atmospheric boiling temperature, but not to its boiling point defined by the tube side pressure. After being heated in the crystallizer heat exchanger, the slurry is discharged to the lower pressure vapor body. The crystallizer slurry flashes (evaporates) to dissipate excess energy the slurry cannot contain (i.e., until the temperature is decreased to the saturation temperature of the slurry at the vapor body pressure). The evaporated water (steam) exits through the top of the crystallizer vapor and flows through the crystallizer entrainment separator to the crystallizer vapor compressor or condensed in a process condenser or used in thermocompressors.

HERO^{TM} - To reduce the energy demand required in a ZLD, some operating facilities have chosen membrane technologies, like the HERO^{TM}. In place of energy to remove dissolved solids, the HERO^{TM} uses chemistry and membranes to reduce wastewater volumes by 85 to 90 percent. A simplified schematic of the system is shown in Figure 3.

Figure 3. HERO™ Flow Diagram



A lime/soda softener is used as the first step of the HERO™ process to remove the majority of hardness in the water and to remove suspended matter in the wastewater. The lime/soda softener chemical requirements include lime, soda ash, coagulant, and polymer. The sludge from the softener is dewatered, and the filtrate returned to the front end.

The lime/soda softener discharge is directed to filtration units to remove additional suspended matter. The backwash from the multimedia filters is directed back to the inlet of the lime softener. The filtrate is fed into a weak acid cation unit for removal of the remaining hardness. The weak acid cation unit regeneration water can be sent directly to the wastewater treatment system downstream of the HERO™ or may be used for pH control in cooling towers or possibly a crystallizer.

The weak acid cation effluent is dosed with acid to lower the pH to 4.5 and directed into a degasifier for the removal of the remaining alkalinity prior to caustic injection to raise the pH to 10.0. With a pH of 10, the feed is sent into the HERO™, where the salts are concentrated and the water is recovered at greater than 90 percent. The high recovery is achievable due to the removal of hardness and the high pH eliminating organic and silica fouling. The clean permeate from the HERO™ can be used in many plant locations, e.g., cooling tower, DI, etc.

EVAPORATION PONDS - Solar evaporation involves the disposal of wastewater in an open pond to utilize the sun's energy to evaporate water, leaving sludge and a concentrated slurry in the pond. Factors affecting the feasibility of solar evaporation include solids (dissolved and suspended) content of the wastewater as it affects sludge accumulation and evaporation rates as a result of increased salinity, atmospheric precipitation, evaporation rates, land availability, and environmental regulations.

IMPORTANCE OF RELIABILITY AND PROPER OPERATION (Handling of Upsets)

ZLD systems are notoriously difficult, costly and time consuming processes to operate and maintain. Many power plants with ZLD systems fail to acknowledge this and consequently struggle with unreliable and less than optimal performance. Furthermore, many companies, including decision-making executives, fail to recognize or understand the importance of ZLD operation and its potential impact on production until it's too late. Unfortunately, this typically leads to the reluctance of companies to allocate the necessary resources to keep it maintained, upgrade systems and equipment and properly staff with dedicated and trained employees.

Success can be derived from diligence and focused attention on every aspect of the ZLD plant with the most important factor that executive and facility management are interested in its reliability. Another important factor in achieving ZLD plant reliability is the ability to not impact the higher goal of generating electricity or other product. ZLD plant reliability can be achieved by:

CONCEPTUAL DESIGN

- Perform a complete water chemistry evaluation on raw water and establish preliminary operating parameters, such as cooling tower operating limits; utilize this data in designing the ZLD system in an effort to specify proper flow rates, pump sizing, chemical applications, sump/tank capacities and metallurgy.
- Account for all operating scenarios during this conceptual phase: one unit offline, start-up, shutdown, cycling operation.
- Establish testing criteria for major equipment performance evaluation to compare to design capabilities, which is often not considered or performed during commissioning,

COMMISSIONING

- During the commissioning phase, ZLD testing can be challenging if the facility is not operational and no seed water is available, therefore consider pre-storage of water, such as a process water storage pond, to support commissioning the ZLD plant earlier in the commissioning process so as to not impact targeted completion milestones and identify issues earlier for EPC corrective action. Inevitably, once the generation plant's performance test is complete, the EPC contractor's focus on ZLD commissioning and correcting deficiencies is significantly diminished, if non-existent.

OPERATIONS

- Recognizing the need for dedicated operation and maintenance staff who are adequately trained and qualified on the ZLD process; properly staff with the right balance of operations and maintenance personnel,
- Company executive and facility management embrace the not-so-popular idea of increasing staffing levels and dedicating the necessary resources to achieve reliability.
- Establishing site-specific equipment operating procedures that accurately document step-by-step operational tasks so that plant operators are consistent in ZLD operations; implement emergency and abnormal response procedures that guide operators on immediate corrective actions,
- Facility staff adopts and embraces a proactive approach towards operation and maintenance by modifying the original design to perform better and raise the level of attention to equal that of the power generating portion of the facility.

Overshadowing all of the processes and the primary factor in the success of any ZLD plant is the program of plant operator training and supervision established in the ZLD plant. The ZLD program should provide for a qualified staff and oversight with the ability to take ownership of the process and continue to improve it while remaining reliable. It is extremely important to have buy in from the corporate level and establish a staffing matrix that includes operators and supervision adequate for the size of the ZLD facility. As an example, a typical 2x1 combined cycle electric generating plant with a ZLD plant equipped with clarifiers, weak acid cation softeners, high efficiency reverse osmosis, crystallizer and belt filter and sludge presses would have four water plant operators for 24/7 coverage and a supervisor or chemist to oversee short and long term operations.

HERO^{TM} plants, in particular, are comprised of four or five highly complex sub-systems with each operating in a daisy chain type formation, meaning that the system before and after must be functioning properly to avoid upset of the downstream systems. Successful operation of the ZLD plant can be achieved with the following considerations:

- HERO^{TM} plants rely heavily on reliable chemistry analysis with tests typically being performed every 4 hours which requires maintaining on-line instrumentation and performing bench top chemistry analysis comparisons,
- ZLD plants can be equipped with hundreds of pumps, valves, sumps and chemical injection points making spare parts availability crucial, which sometimes can be hampered by long lead times and rare metallurgy; an adequate supply of spare parts is vital to plant reliability,
- Select a qualified chemical services provider who is experienced in ZLD applications that can provide the necessary guidance and formulation of chemicals that work well with the process,
- Establish alliances with the original equipment manufacturers of major machinery and control systems as well as third party maintenance service companies to support maintenance of critical systems,
- Establish a preventative maintenance program that reduces reactive and emergent maintenance

Measuring the cost of a forced outage can be staggering to an already costly operation. For example, consider a forced outage on a 25 gpm ZLD crystallizer for a 24-hour period. At 25 gpm x 60 min/hr x 24 hrs/day = 36,000 gallons of process water that requires temporary storage or off-site disposal. If off-site disposal is utilized, at an estimated $0.30/gal, it would cost $10,800 per day to dispose of process water off-site at a remote reclamation facility. With no action, the cooling tower chemistry will elevate and eventually exceed the maximum limits for equipment protection. More importantly is that it can ultimately lead to lost revenue if the generating units are reduced in output or completely removed from service.

With a good understanding of ZLD system theory and the importance of proper operations of the systems, an examination of what is required will assist in framing the operating expectations for future ZLD installations.

BARE ESSENTIALS (Power, Chemicals, Solids Handling)

ZLD systems operate by removing dissolved solids from wastewater. This process goes against the unique ability of water to be a universal solvent. To overcome this ability, power, chemicals, and handling of the produced solids are required. Quantifying each of these “bare essentials” is helpful when evaluating a ZLD technology.

POWER - The energy required to remove dissolved solids is supplied in different forms depending on the ZLD technology. For a HERO^{TM} system, the energy is pump power to overcome osmotic pressure and separate the salts across a membrane. A brine concentrator and crystallizer use steam or vapor compression to evaporate water, leaving a salt slurry behind.

An estimation of the power demand for a typical 300 gpm system was determined using operating data from a HERO^{TM} and power use guidelines for a BC and crystallizer. The power estimate is outlined in Table 1.

Table1. Average Power Requirements – 300 gpm System (kW)

BC	HERO^{TM}	Crystallizer
1,260	160	3,600

Power is not the only resource needed for ZLD systems, chemicals are also required to separate solids, remove scaling constituents, or condition the water for treatment.

CHEMICALS - The BC process, in general, is not a chemical feed intensive process. Acid and possibly bleach are needed in the BC feed tank to condition the water for the deaerator. Caustic may be required in the BC sump to control pH. Antifoam may also be required in the sump for foaming control.

Crystallizers typically require even less chemical feeds than a BC, typically needing anti-foam feed for the evaporator vessel only.

HERO^{TM} systems, in contrast to the BC, require chemicals in several steps, including multiple applications of acid and caustic. Additionally, lime, soda ash, bleach, coagulant, sodium bi-sulfite, polymer, and anti-scalant are all needed for the HERO^{TM} operation.

Chemical demands for each treatment system will vary depending on inlet water quality. For the basis of this paper, an inlet water quality similar to many plant wastewaters, which consist mainly of cooling tower blowdown, was chosen and is defined in Table 2.

Table 2. ZLD Makeup Water Quality

Constituent	mg/L
Calcium as $CaCO_3$	550 – 600
Magnesium as $CaCO_3$	250 – 275
Sodium as $CaCO_3$	800 – 850
M-Alkalinity as CaCO3	40 – 50
Sulfate as $CaCO_3$	820 – 900
Chloride as $CaCO_3$	780 – 850
Silica as SiO_2	40 – 50

Based on this inlet water quality, for a 300 gpm ZLD system, the estimated normal chemical demands are described in Table 3.

SOLIDS HANDLING - The solid waste of the ZLD systems must be dewatered prior to disposal. Solids disposal for a HERO^{TM} is significantly greater than that of a BC or crystallizer, due to the solids precipitated in the softener and additional dissolved solids added in the process chemical feeds that end up in the crystallizer.

Table 3. Average Chemical Requirements – 300 gpm System (lb/yr)

Chemical	BC	Crystallizer	HERO^{TM}
Acid	92,000		335,000
NaOH	10,000		30,000
NaOCl	27,000		27,000
Coagulant			60,000
Polymer			5,500
Lime			320,000
Soda Ash			1,250,000
Anti-Foam	5,000	10,000	
Antiscalant	10,000		6,700
Sodium Bi-Sulfite			3,500

A comparison of solids handling cannot be performed on a unit by unit basis, as a BC does not produce a dewatered solid typically. Therefore, the solids handling is described as a combination of unit operations in Table 4.

Table 4. – Average Solids Disposal - 300 gpm ZLD System (tons/yr)

BC/Crystallizer	2,700
HERO^{TM}/Crystallizer	3,650

To operate the power systems, chemical feeds, and dewatering equipment requires manpower. To quantify the complete picture of the ZLD operating requirements, the manpower must be defined.

ANALYSIS OF MANPOWER

The amount of manpower required for each ZLD process, can be analyzed by defining key operator activities and assigning a unit of time needed for each. The total time needed for each ZLD can then be estimated based on the need for each activity in the ZLD. This quantitative estimate can then be compared with a survey of successfully operating ZLD plants to calibrate the model.

The key ZLD operating activities were defined as:

- Lab work
- Control Board
- Solids Handling
- Chemical Feeds / Online Cleaning
- Troubleshooting / Implementing Solution
- Supervisory

LAB WORK - Due to the minimal chemical feeds in an evaporative process, BC and crystallizer plants do not have extensive laboratory needs. Typically, feedwater and slurry pH, conductivity, TDS, total suspended solids, and chlorides are monitored once a shift.

While one set of samples per shift is normal for an evaporative process, the HERO^{TM} sampling is much more involved. Based on actual plant operations and consistent with recommended O&M manuals, a HERO^{TM} requires 11 grab sample locations with a total of 23 analyses. Critical analyses are taken every 4 hours to maintain chemistry. A proper lab with technician area suitable for managing these samples is needed for these plants.

Actual plant lab work was observed to develop time units for each activity and analysis, and these observations were used in the manpower calculation.

CONTROL BOARD - Monitoring of the ZLD system variables and control points is difficult to quantify. The range of use varies from day to day. For the purpose of this study, it is assumed 20 minutes of every hour an operator observes ZLD operations, acknowledges alarms, and performs general control responsibilities at the system control board for each system.

SOLIDS HANDLING - Handling of dewatered solids requires additional operator attention. This can include watching a press, observing a belt, moving dewatered solids or containers, or coordinating hauling of the waste. These activities do not demand a large amount of time, but must be accounted for with the crystallizer and HERO^{TM} systems.

CHEMICAL FEEDS/ONLINE CLEANING - In an application where water hardness must be controlled to keep a plant online, maintaining dry chemical feed accuracy can be critical and require operator attention weekly if not daily to maintain. Feeders can plug, hoses and/or pipe can plug, pH probes can scale and must be kept clean.

Other chemical feed pumps require daily or weekly calibration.

As crystallizer performance dictates, online cleaning is required periodically, possibly weekly. During an online cleaning, the operator must manage the plant wastewater and other plant operations which may require additional assistance. Offline cleaning can be even more demanding on manpower and further decrease unit availability.

TROUBLESHOOTING - Most water treatment processes require some level of troubleshooting to maintain plant performance. The complication of a ZLD process is that the troubleshooting can lead back to the original water supply, to the plant pretreatment, the cooling towers, the chemicals, and the ZLD.

To quantify the amount of time needed to troubleshoot a system, the pieces and parts in the system that require attention must be identified. Three components of each ZLD which may need adjustments during operation are control loops, on-line water analyzers, and chemical feed accuracy.

For a typical BC plant, there are 9 control valves, 4 on-line water quality analyzers, and 3 chemical feeds. A crystallizer may contain 6 control valves, 2 on-line water quality analyzers, and 2 chemical feeds. While a HERO^{TM} system can include 14 control valves, 15 on-line water quality analyzers, and 11 chemical feeds.

The time required for troubleshooting can be proportioned to the amount of each device identified for the ZLD system.

Once a solution is identified, a fix must be implemented. This may be accomplished by the operator or may involve additional departments, taking additional time and manpower.

SUPERVISORY - Keeping a ZLD plant online demands coordination with the production facility, planning for shutdowns, chemical supplier coordination, environmental reporting, and assisting with watching the plant operations while normal lab work or plant maintenance is performed. These tasks can be summarized as supervisory tasks and quantified as such.

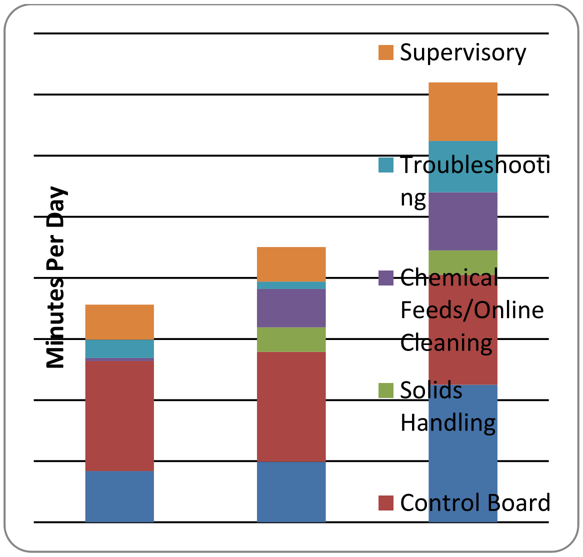
ANALYSIS - Based on the results of the time analysis described and the calibration with successfully operating plants, the manpower required for the ZLD systems were summarized and provided in Figure 4.

Operations staff for a ZLD may vary from a half full time equivalent to two full-time equivalents for a single train, depending on the unit operations included. In addition, electrical and mechanical maintenance will be required to be staffed for the systems. These staffing levels should be carefully planned for when considering ZLD.

REDUCING OPERATING DEMANDS

Reliability and manpower are at a premium for ZLD systems. Increasing reliability while reducing manpower is a benefit all plants would like to achieve. The good news is that it may be possible. ZLD systems keep product going out of the door by treating plant wastes. If you can disconnect the plant output from the ZLD system, the reliability demands and risks can be reduced.

Figure 4. Analytical Analysis of ZLD Manpower



A fairly inexpensive means of disconnecting the product from the ZLD system is to provide a large reservoir between the plant and the ZLD. This will allow a ZLD system to be shut down for a predefined timed period while allowing the unit to continue to operate. A secondary advantage of a reservoir is to reduce feedwater chemistry impacts to the ZLD by leveling water quality. In particular, many ZLD systems receive cooling tower blowdown and/or ion exchange waste. Cooling tower blowdown fluctuates from day and night or full load to partial load operations. Ion exchange waste is typically an order of magnitude more concentrated than other typical waste streams. Change in chemical composition in the feed to the ZLD requires operators to be in tune with how this changes the operations.

Another means of lowering the ZLD reliability demand, although in most cases more costly, is the use of temporary volume reduction systems, like portable RO’s and tanks to treat or store wastewater when a ZLD is offline.

A costly means of reducing the operating reliability risks of a ZLD system is to provide redundancy of the ZLD. Due to poor turn down capability of these types of systems and the costly alloy required, 2 x 50% or another configuration of redundancy should be considered before proceeding with a 2 x 100% system configuration.

CONCLUSIONS

ZLD systems play an important role in industrial and power plants across the United States right now and as water discharge regulations continue to tighten, more plants will need to understand and implement ZLD systems. Installation of these systems is a major capital and operational responsibility and plant's need to understand the risks and demands. Similar to the EPA's awareness that in Arizona, 7.85 gallons of water are lost to evaporation per kWh consumed[1], the ZLD users should be aware it can require 0.8 kWh of power, 0.1 pounds of chemical, and up to 2 operators to recycle 7.85 gallons of water in a ZLD.

REFERENCES

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