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AN ECONOMICAL NEW ZERO LIQUID DISCHARGE APPROACH FOR POWER PLANTS

Charles H. Fritz, Black & Veatch Corporation, Kansas City, Missouri
C. K. Tiwari, Aquatech International Corp., Canonsburg, Pennsylvania

ABSTRACT

Zero liquid discharge designs are becoming common place in the power industry. Drivers are environmental restrictions on discharges, limitations on water supply, and the need to expedite permitting of generation facilities.

The High Efficiency Reverse Osmosis (HERO™) process offers a cost-effective solution for the recovery and reuse of wastewater including cooling tower blow down streams. This results in efficiency enhancement through increased cycles of concentration of the cooling tower and also reduces the size of the disposal pond or a thermal concentration system.

HERO is a membrane process with a modified pretreatment scheme to accommodate high concentrations of dissolved solids including silica. It has been commercially tested with silica levels in excess of 1600 ppm in the reject. Cooling tower blowdown recovery with the process is potentially more than 90% since the process is limited only by osmotic pressure. The process is also resistant to organic and biological fouling, which could potentially be present in the wastewater streams.

A new power plant in Arizona utilizes the HERO process to treat high silica cooling tower blowdown and process wastewater. The high purity product water is recycled back to the cooling tower thus reducing the fresh makeup water requirement and reducing wastewater volume. Part of the product water may be further polished and used as boiler make-up. The reject stream, which is about 12 % of the original blowdown volume, is discharged to a disposal pond. The design resulted in substantial savings in capital and operating cost in achieving Zero Liquid Discharge in addition to maximizing the reuse of raw water.

INTRODUCTION

The trend toward zero liquid discharge (ZLD) design of power stations is increasing. The reasons for this trend include limitations on water availability, increasing concern for conservation of fresh water supplies, more restrictive discharge limitations, and a need to expedite the permitting process for new generating facilities. ZLD facilities address both the environmental and political concerns and are less costly and more efficient than alternative air-cooled condensers.

Power generation is a water intensive process with most of the water used for condenser cooling. The degree of water reuse in the cooling towers is limited by dissolved solids in the water, primarily calcium hardness and silica. Most of the wastewater produced by power plants is cooling tower blowdown. Silica concentrations frequently limit the cycles of concentration in the cooling tower circulating water. This is particularly true in regions of volcanic origin such as the Western and Southwestern states and Mexico. The result is high blowdown rates and more wastewater for disposal.

Until recently, alternative treatment methods used to achieve ZLD consisted of combinations of thermal and membrane processes, sometimes coupled with evaporation ponds. These processes include reverse osmosis (RO), electrodialysis reversal, brine concentrators, crystallizers, and spray dryers. While systems of this type have been applied successfully, they represent a significant capital and operating cost expenditure.

The subject of this paper is an innovative new membrane process that has the potential for significant improvement in the economics of ZLD systems. The new process is a high efficiency reverse osmosis process referred to as HERO™. Experience with the HERO process on cooling tower blowdown and other high silica waters has demonstrated that recovery rates on the order of 90% are possible(1,2,3). The process can be used as a preconcentrator ahead of a thermal evaporation system or as the sole volume reduction device prior to discharge of the concentrated reject stream to an evaporation pond or other means of disposal.

PROCESS DESCRIPTION

A simplified schematic of the HERO process as applied to cooling tower blowdown treatment is shown in Figure 1.

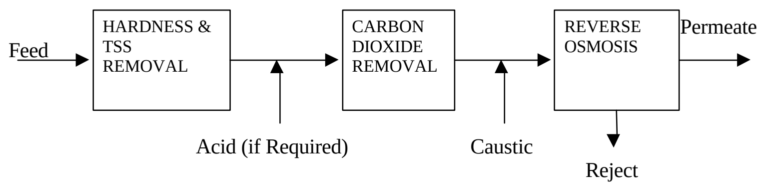

Fig. 1 – HERO Process Schematic

The basic process consists of three steps.

- Hardness and suspended solids removal
- Carbon dioxide removal
- RO treatment at elevated pH

Pretreatment steps that make up the HERO process are customized depending on the water chemistry and site specific design criteria. The one step that remains constant is the RO operating at elevated pH. In order to operate the RO at elevated pH, all hardness and other cationic species that would scale the membranes are removed. Suspended solids concentrations are maintained near zero to minimize membrane plugging. Carbon dioxide is removed to the extent practical to minimize buffering. Silica is highly soluble at elevated pH as shown in Figure 2 and therefore does not limit the recovery of the RO unit. In theory, the percent recovery achieved by the RO, after pretreatment, is limited only by the osmotic pressure of the reject. Operating experience has shown that the process can achieve recoveries of 90% and higher for most cooling tower blowdown applications.

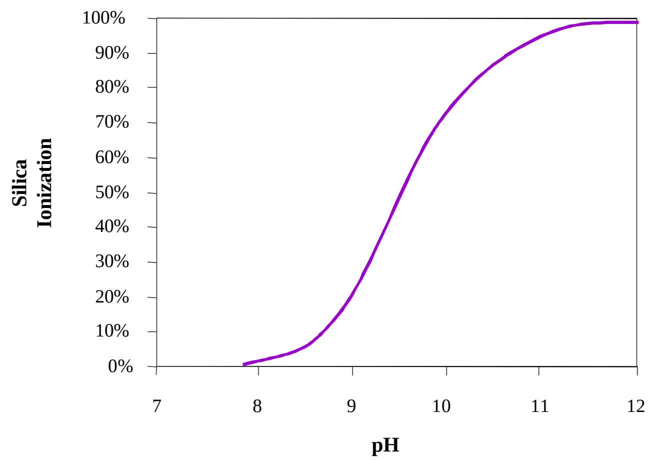

Figure 2. Silica Ionization Curve

The preferred hardness removal method for high TDS cooling tower blowdown consists of conventional lime-soda softening followed by filtration and weak acid cation (WAC) ion exchange. Other hardness removal methods may be feasible depending on site specific conditions. Lime-soda softening in a conventional solids contact clarifier is an economical method of removing the bulk of the hardness (calcium and magnesium) and other scale forming cations such as barium and strontium. The effluent from the clarifier is filtered with dual media gravity or pressure filters for reduction of suspended solids.

WAC ion exchange, when operated in the hydrogen cycle, will efficiently remove hardness associated with alkalinity. Alkali addition may be needed for adjustment of the hardness to alkalinity ratio in the feed water. Hydrogen ions released in the cation exchange reaction react with the alkalinity to form carbonic acid for subsequent removal in the degasifier. The WAC units remove the remaining hardness to less than 0.2 mg/l as required to prevent scaling of the membranes[5].

Acid is injected into the WAC effluent to neutralize any remaining alkalinity. A forced draft degasifier or other means of degasification are employed to remove the resulting carbon dioxide.

The RO system is operated at a pH approaching 11.0 in the RO reject. Control of pH is by injection of sodium hydroxide (liquid caustic) into the RO feed water. The pH limitation of 11.0 is established by manufacturers of commercially available thin film composite membranes.

High purity RO permeate is directed back to the cooling tower or may be used as cycle makeup after additional treatment. The highly concentrated RO reject may be disposed of in an evaporation pond if the plant is located in an arid region. Where evaporation ponds are not feasible, it may be necessary to direct the stream to a crystallizer or spray dryer with landfill disposal of the dry solids.

HERO PROCESS ADVANTAGES

The HERO process combines several industry proven treatment steps into a single process which has the ability to treat difficult water at high recoveries and increased flux rates. The advantages of the process compared to conventional RO are summarized below.

- Scaling of the RO membranes is eliminated by pretreatment to remove hardness, carbonate alkalinity, and other scale forming constituents in the feed water.
- Silica polymerization is avoided by operating at high pH. Operation with silica concentrations in the range of 1600 to 2000 mg/l in the reject have been demonstrated [2] compared to a limit of about 150 mg/l silica in the case of conventional RO.
- Biological fouling is eliminated at the high pH. The high pH serves as a biostat to control biological fouling. Bacteria, viruses, spores, and endotoxins are either lysed or saponified at the operating conditions.[4]
- Organic fouling is reduced as organics are either emulsified or saponified at the high pH and do not adhere to the membranes.
- Particulate fouling is substantially reduced due to a reduction in surface tension (low beta potential) at high pH. Operating experience indicates that water with high silt density index (SDI) values can be treated without frequent chemical cleaning.
- Tolerance to occasional low levels of oil and grease in the feed water without interruption of operation.
- Operation at high pH protects the RO membranes from attack by chlorine in the cooling tower blowdown by neutralizing the hypochlorous acid content. However, dechlorination is required for protection of the WAC resin.

- Removal of scaling constituents in the pretreatment steps eliminates the need for scale inhibitors in the RO.

The HERO process addresses the root causes of fouling and scaling of RO membranes. The result is that the process is capable of operating reliably at 90% or greater recovery unlike conventional RO that typically operates at 75% or lower recovery. Application of the process as a preconcentrator on cooling tower blowdown reduces the waste volume by a factor of 10 or greater. The relatively small quantity of reject can be directed to a solar evaporation pond or treated further with a small brine concentrator and/or crystallizer.

The inherent resistance to scaling, fouling and plugging mechanisms enable the HERO process to operate at higher flux rates than conventional RO. Flux rates in the range of 25 to 35 GFD are possible compared to 10 to 12 GFD used for traditional RO. The higher flux rates mean fewer membranes, increased membrane productivity, and lower membrane replacement cost.
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Another advantage of the process is it that the system can be safely shut down without concern for biofouling. This feature is important for merchant power plants that operate based on energy demand in the market place.

ECONOMICS OF ZLD ALTERNATIVES

The first full scale ZLD installation based on the HERO process was installed and has been operating successfully since the summer 2001. This 500 MW combined cycle power plant located in the Arizona utilizes high silica well water for cooling tower makeup. The cooling tower blowdown treatment system is designed to process approximately 300 gpm with an overall recovery of 88%. Permeate from the RO is reused in the cooling tower with provisions for possible future use as a source of makeup to the steam cycle after additional treatment. RO reject and miscellaneous wastewater from the pretreatment steps are directed to an on-site disposal pond.

An engineering analysis of the HERO based system and a brine concentrator treatment system was performed to determine the comparative costs of the alternative ZLD systems considered. Estimated comparative installed costs are illustrated in Table 1. Table 2 is a summary of the estimated annualized operation costs for the two systems.

	HERO w/ Evaporation Pond, $ x 1000	Brine Concentrator w/ Evaporation Pond, $ x 1000
Equipment, Installed	3,150	5,250
Buildings	525	525
Sitework	275	230
Electrical	100	170
Evaporation Pond	2,400	1,200
Total Direct Cost	6,450	7,375
Indirect Cost	1,950	1,990
Total Installed Cost	8,400	9,365
Differential Cost	Base	965

Table 1. Estimated Comparative ZLD System Costs

	HERO w/ Evaporation Pond, $ x 1000	Brine Concentrator w/ Evaporation Pond, $ x 1000
Power Consumption	48	700
Chemicals	175	28
Operation & Maintenance	206	250
Consumables	8	Nil
Total Operating Cost	437	978

Table 2. Estimated Annual Operating Costs

The capital cost estimates indicate that the brine concentrator based system is roughly 10% more expensive than the HERO based system. Annual costs for the two systems indicate a significant difference in favor of the HERO based system. Although the HERO system has a higher chemical consumption cost, the brine concentrator power consumption more than offsets this difference. Total annual operating cost differential is estimated to be over $500,000 in favor of the HERO based system assuming a power cost of $0.05/kWh. The net present worth, assuming 3.5% escalation and a period of 15 years, is calculated to be approximately $7,000,000 in favor of the HERO based system.

CONCLUSIONS

The HERO process consists of several tried and proven pretreatment steps in combination with reverse osmosis operating at high pH. The resulting process has several features that make it particularly well suited for the treatment of cooling tower blowdown for recovery of waste water or as a preconcentrator for zero liquid discharge. Attractive features include robust self-cleaning operation, the ability to concentrate dissolved silica to 1600 mg/l and higher, feedwater recovery of approximately 90%, and the suitability for start-stop operation.

HERO based ZLD systems have now been installed and are operating successfully in two combined cycle power plants. The process has the potential for significant cost savings when used for treatment of cooling tower blowdown.

The primary cost advantage of HERO based ZLD systems when compared to brine concentrator based systems is improved energy efficiency. A net present value analysis shows an economic advantage of about $7 million for a typical 500 MW combined cycle power station over a period of 15 years.

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