APPLICATION OF MEMBRANE CAPACITIVE DEIONIZATION TECHNOLOGY IN COOLING TOWERS

Introduction

Cooling towers provide cooled water for applications ranging from heating, ventilation, air-conditioning, and industrial processes. Stored heat in the recirculation water of the cooling tower is released through the process of evaporation and as the water evaporates, the solids that are dissolved in the water are left behind. As a consequence, concentration of dissolved solids in the cooling tower increase over time and it may result in corrosion and scaling because of high concentrations of chloride, calcium, and alkalinity. In order to reduce the scaling and corrosion potential in the cooling tower, it is common practice to add chemicals such as antiscalants and corrosion inhibitors to the recirculation water.

Once the conductivity of this water reaches a certain threshold value, it is discharged as a blowdown stream. This process leads to a discharge of large volumes of wastewater containing high levels of chemicals, which has a significant environmental impact when not properly disposed. In order to minimize this discharge of wastewater and use of chemicals, total dissolved solids (TDS) from the recirculation water need to be removed. TDS removal from the recirculation water can be achieved by deionizing the recirculation water, deionizing the feedwater that enters the cooling tower, or deionizing the blowdown water.

The use of reverse osmosis (RO) (1-3) has been suggested for deionization of the cooling tower recirculation water and for deionization of the blowdown water. The use of RO seems to be impractical because of low water recoveries as well as other technical drawbacks, such as silica fouling on the membranes. Furthermore, the cooling tower recirculation and blowdown stream contains high levels of foulants, requiring extensive pre-filtration steps such as ultrafiltration to prevent membrane fouling (2, 3).

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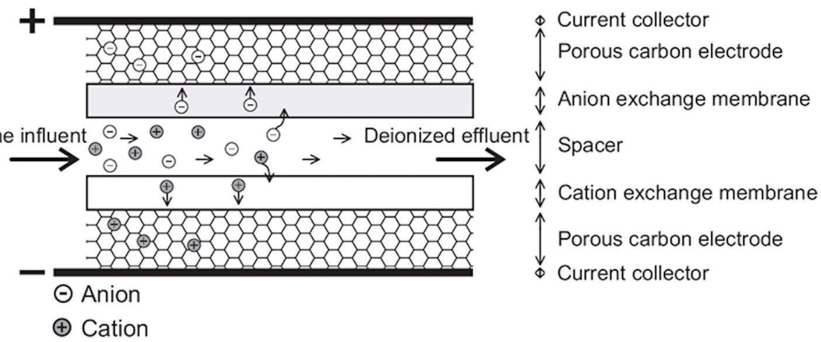

Figure 1. Schematic representation of the different components of a MCDI cell (Reference 10).

There is an alternative and innovative method to reduce the chemicals and water use of a cooling tower by deionizing the feedwater by membrane capacitive deionization (MCDI). MCDI uses capacitive electrodes and ion-exchange (IX) membranes to remove ions such as chloride and calcium from various water sources, including, tap, well, and even seawater (4-9). The key difference between MCDI technology and standard capacitive deionization (CDI) technologies is the use of IX membranes, which translates into much higher ion removal efficiencies and water recoveries (5, 6, 8).

In addition, the IX membranes increase the ion storage capacity of the carbon electrodes by up to 40% because of the additional ion storage capacity that is available inside the macro-pores (pores greater than >50 micron [µm]) of the carbon electrodes (6). Furthermore, the membranes reduce the sensitivity of the electrodes for scaling and fouling by forming a physical barrier between the fouling-sensitive electrodes and the flow channel, resulting in a greater lifetime of the MCDI module.

MCDI, because of its tunable salt removal, ability to start without long start-up sequences, and high water recovery, can be implemented on the make-up water, which is in contrast to RO systems that are installed on the recirculation loop or blowdown water. There are four distinct advantages of MCDI compared to RO for the cooling tower application; the first being that it has a low fouling potential to silica. The second is the high water recovery, often above 80%. This equates to a more efficient use of the feedwater and higher overall water savings in the cooling tower system. The third advantage is that MCDI requires minimal pre-filtration compared to RO (10). The fourth benefit is the low energy use, allowing for lower operational costs (11).

The objective of this article is to demonstrate the feasibility of MCDI to produce desalinated water for cooling tower makeup. An additional focus is to demonstrate that MCDI is a robust technology that can treat raw river water (Black River, OH, USA) with minimum pre-filtration and cleaning.

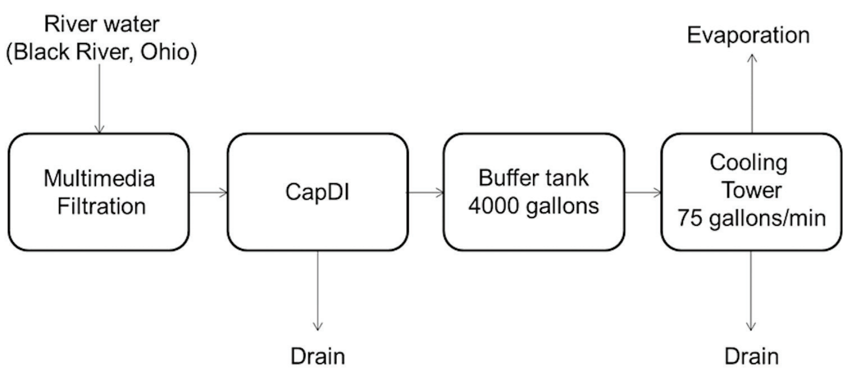

Figure 2. Schematic representation of the different process steps of the installed system.

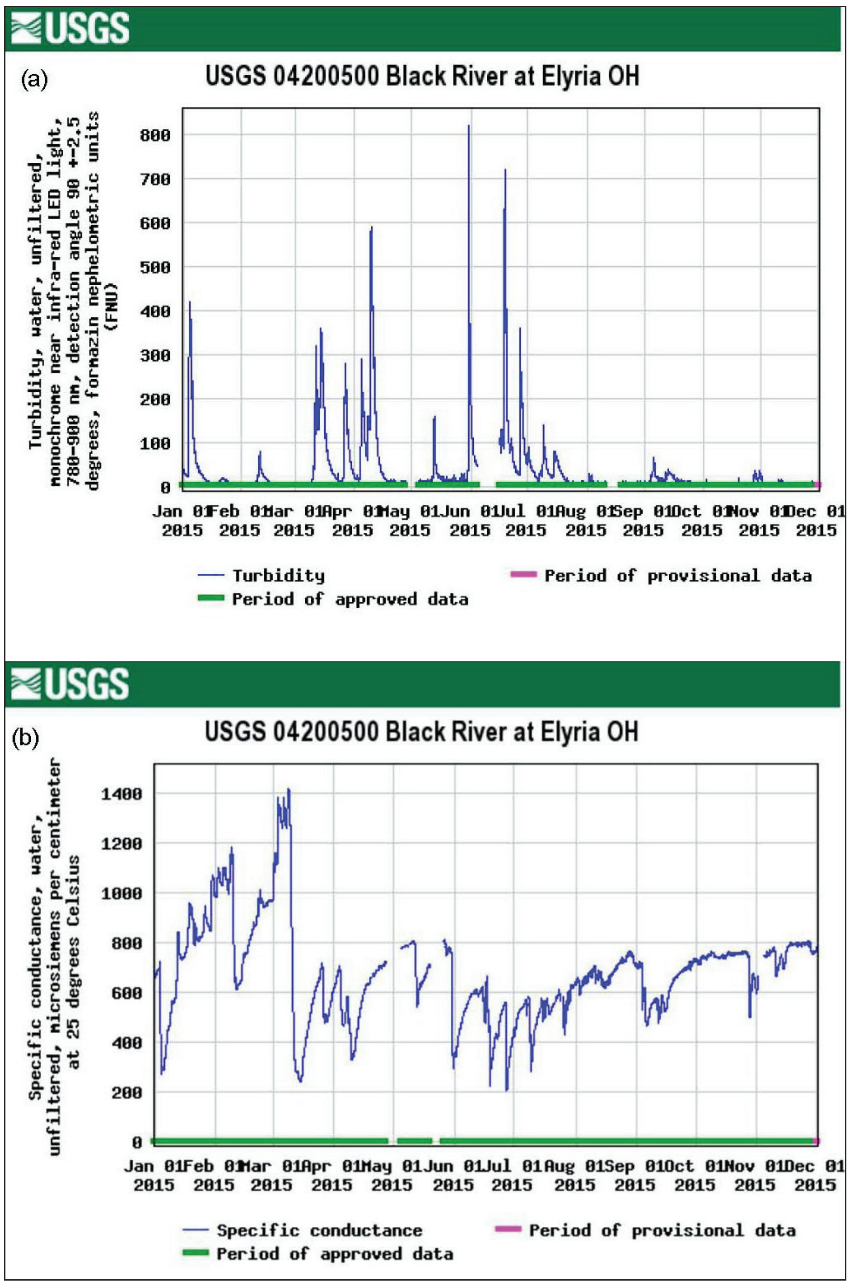

Figure 3. Raw river water turbidity (a) and specific conductivity (b) over the time (Reference 12).

Experimental

MCDI module. The MCDI system and modules used in this application were made by the equipment manufacturer[B]. An MCDI module consists of a housing that contains multiple stacks of parallel unit cells. Each unit cell consists of two porous carbon electrodes separated from each other by a spacer. On top of the electrodes, IX membranes are placed so that the anion-exchange membrane is on top of the anode, and the cation-exchange membrane is on top of the cathode. The electrodes are connected to thin graphite sheets, called current collectors. The spacer between the membranes acts as a flow channel to allow passage of the water to be desalinated. A schematic representation of a unit cell is given in Figure 1.

System configuration. An MCDI system[A] with 36 modules was installed at the Republic Steel factory located in Lorain Ohio, USA. This system was set to produce 75 U.S. gallons per minute (gpm) of product water. The settings of the system were adjusted during the operation to allow for a constant reduction in TDS to reach the target product water requirements. This was necessary to take into account the variation in the conductivity of the effluent water. The MCDI system employed a simplistic, low-cost, low-maintenance multimedia filter for its pretreatment. To counteract the seasonal water quality changes (TDS variation) the manufacturer employed a smart dynamic control system that ensures the ionic removal is constant. Additionally, the capacitive DI system was equipped with a fully automated smart clean-in-place (CIP) system, which ensured that modules were kept clean without constant operator intervention as can be needed with other membrane technologies.

Feedwater quality. The raw river water from the Black River, OH (USA) was monitored over the 10-month period. Figure 3 (12) shows turbidity spikes up to 800 Formazin Nephelometric Unit (FNU) (Nephelometric Turbidity Unit [NTU] equivalent) and specific conductivity spikes up to 1,400 microsiemens per centimeter (µS/cm).

TABLE A
Characterization of Raw River Water and Required Cooling Tower Water Quality

		Black River			Cooling Tower Water Specs	MCDI pure
Parameter	**Unit**	**Min**	**Max**	**Avg**		
pH	(-)	6.8	8.1	7.5	–	–
MO alkalinity	(mg/L HCO_3)	65	148	112	–	–
Conductivity	(µS/cm)	300	1,300	570	< 2,000	305
Dissolved solids	(mg/L)	175	690	335	–	–
Suspended solids	(mg/L)	8	520	67	–	–
Total solids	(mg/L)	295	820	420	< 10	6
Bicarbonate alkalinity	(mg/L HCO_3)	71	144	111	–	–
Chloride	(mg/L)	17	180	50	< 50	22.5
Sulfate	(mg/L)	55	140	90	< 50	32.5
Silica	(mg/L)	2	8.4	5.2	< 150	NM
Nitrate	(mg/L)	9.6	18.5	14.4	–	–
Ortho phosphate	(mg/L)	0.1	0.45	0.2	< 0.2	0.1
Hardness	(mg/L $CaCO_3$)	120	260	185	–	–
Calcium	(mg/L $CaCO_3$)	77	188	133	< 500	29.2
Magnesium	(mg/L)	7	20	13	< 200	15.2
Sodium	(mg/L)	19	118	40	–	–
Iron	(mg/L)	0.05	1.6	0.52	< 0.5	NM
Zinc	(mg/L)	0.017	0.2	0.075	< 0.05	NM
Copper	(mg/L)	0.05	0.05	0.05	< 0.1	NM
Ammonia	(mg/L)	1	19	2.27	< 0.2	NM
Oil and grease	(mg/L)	1	26	2.9	< 5	NM
TOC	(mg/L)	1	32	11.5	< 5	NM

*NM = Not Measured

Table A shows the characterization of the raw river water. The high level of suspended solids and organic content are favorable for system fouling and would be problematic for RO. The cooling tower requirements and produced water by MCDI system are also listed in Table A.

Results and Discussion

MCDI performance. Figure 4 provides data on the average conductivity of the filtered river water that was fed to the MCDI system, and the average conductivity of the purified water during the test period of one month. The figure also shows that the MCDI system was operated at a constant removal of greater than 40% and it was achieved despite varying inlet water conductivity. The water recovery of the total system, which is defined as desalinated water flow divided by inlet water flow multiplied by 100%, was ca. 85%, meeting the desired performance target.

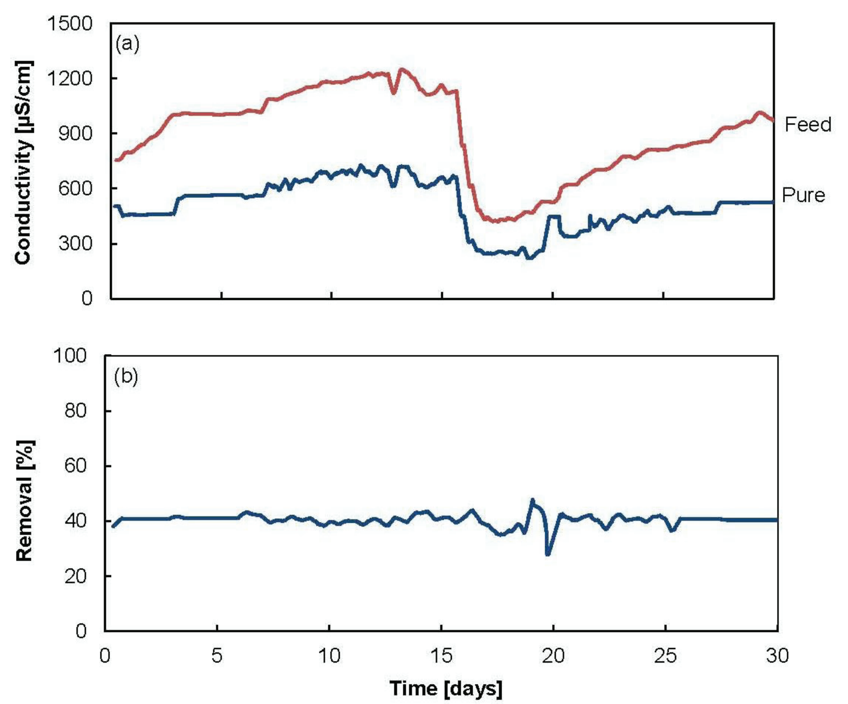

Figure 4. Average conductivity of the feedwater and produced water (a), and ionic removal over a period of 30 days (b).

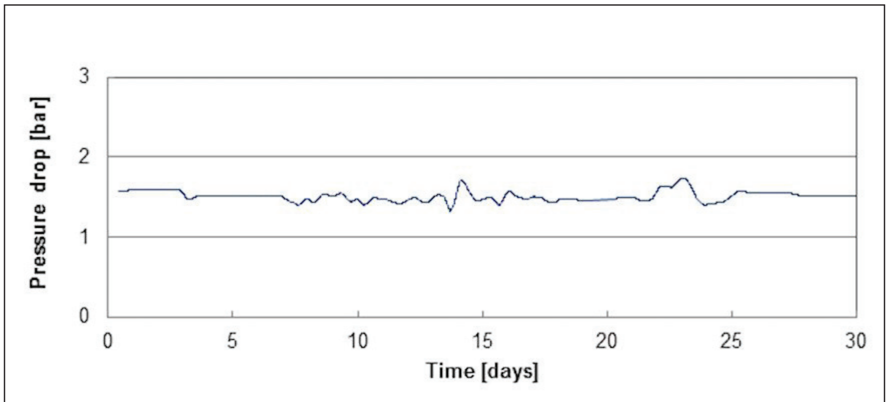

Figure 5. Pressure drop of the MCDI system over a 30-day period.

The energy use of the total system, including pumping energy, process control, and measurement equipment was below 0.7 kilowatt hours per cubic meter (kWh/m^3) of water produced. The energy use of the MCDI module itself was approximately 0.4 kWh/m^3 of water produced.

Figure 5 presents the pressure drop over the MCDI system during the last 30 days of operation. The figure shows that the pressure drop is stable over the monitored period of 30 days, which demonstrates that the MCDI system can be used to treat raw river water with minimal pre-filtration. Modules were cleaned-in-place by a fully automated smart CIP system on a weekly basis.

Conclusion

This article shows that MCDI technology is capable of delivering stable make-up water to the cooling tower system using raw river water as a feed source with minimal pre-filtration. Fouling and scaling over a period of 30 days was absent. The treated water quality was always within the cooling tower water specification. The energy use of the total system, including pumps, process control, and measurement equipment was 0.7 kWh/m^3 of water produced of which an MCDI module[A] consumed approximately 0.4 kWh/m^3.

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Endnotes

[A] The Membrane Capacitive Deionization Technology referred to in the text has been developed and commercialized by Voltea B.V. of Sassenheim, The Netherlands. The name of the commercialized product referred to in the article is the Voltea Industrial Series (IS) CapDI© system.

[B] Voltea B.V. is the manufacturer referred to in the text.

Author Piotr Dlugolecki, PhD, leads the technology team that converts Voltea's capacitive deionization technology into commercially viable products. He holds an MSc in chemical engineering and a PhD in membrane technology. Dr. Dlugolecki has published 6 scientific papers and filed 9 patents.

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Author Carlos Camero has two decades of experience in the water treatment industry from a variety of commercial and technical roles within leading organizations going through rapid change. His career spans Veolia Water, GE Water, and most recently Energy Recovery (ERI), where he was responsible for global sales of products and services for mega desalination plants 50,000 m^3/day capacity and above. Mr. Camero has a BS in chemical engineering and is Six-Sigma Quality certified.

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