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ORIENTAL JOURNAL OF CHEMISTRY
An International Open Access, Peer Reviewed Research Journal

www.orientjchem.org

ISSN: 0970-020 X
CODEN: OJCHEG
2023, Vol. 39, No.(2):
Pg. 475-482

Water Conservation in Thermal Power Plant by Using Combination of Membrane treatment and Deionization Route

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http://dx.doi.org/10.13005/ojc/390229

(Received: February 07, 2023; Accepted: April 19, 2023)

ABSTRACT

The modern desalination process for saving water is membrane capacitive deionization in which voltage is applied between two opposite-charged carbon electrodes. An ion exchange membrane is set beside each electrode, and a spacer is placed between them to carry the treated water. The current study shows water conservation along with the reduction in chemical treatment costs in cooling towers with seawater in circulation. Chemical savings of approximately 80% might be achieved by monitoring the cooling tower's water usage and comparing it to a situation without Membrane Capacitive Deionization (MCDI. Furthermore, 24% water reductions, as well as 44% saving in terms of wastewater, are possible. MCDI in range 0.15 & 0.25 kWh/m^3 of generated Low Salt Water (LSW) for cooling tower inlet water. Due to the absorption of calcium and chloride ions, the chances of scaling and corrosion decrease significantly which helps in water and chemical savings.

Keywords: Water conservation, Membrane, Chemical saving, Cooling tower.

INTRODUCTION

Generally, Cooling Towers (CT) in a power plant are used to disperse heat. There is recirculation in the cooling tower and the heat generated is discharged by evaporation. Due to evaporation dissolved ions are held in the system and additionally, the makeup of water is done by a feed pump. Thus, the concentration of water continuously increases in the system. The chloride ions and alkalinity continuously increases which leads to corrosion in pipes. To minimize corrosion and scaling in system chemicals like antiscalants. There is huge damage to the environment if a large number of chemicals and wastewater are not disposed of by proper methods. Removal of calcium and magnesium salts from the water leads to a large proportion of CT water that may be evaporated earlier than conductivity reached to limit value, which reduces the need for chemicals in cooling towers. As a result, less frequent blowdown is required, allowing for the conservation of chemicals and water. Various methods for removal of salt water from the recirculation of cooling tower water are as follows.

(1) Recirculation of deionized water, (2) Blowdown water deionization (3) Feed water deionization before inlet in cooling tower. The treatment

for blowdown water and cooling tower water generally reverses osmosis has been used. But there are certain limitations like less water recovery, and scaling of membranes due to colloidal silica. Also, there are the chances of fouling in the membrane can be observed if there is no proper pre-treatment in done like ultra filtration[14,15]. In this paper, we suggest an alternate approach for reducing the water consumption as well as treatment cost of a Cooling Water (CW) by making up water deionizing by using Membrane Capacitive De Ionization. MCDI is a new de-salination method that is used in capacitive electrodes and ion-exchange filter membranes successfully. This membrane will remove Chloride and Calcium ions from different sources of water like rivers, ground, and saltwater[7,11]. The current study suggests water conservation and chemical cost reduction by applying capacitive deionization in feed water. The membrane capacitive method used capacitive electrodes. The calcium and chloride salts can easily be removed from the water source.Apply of ion exchange membranes in membrane capacitive deionization can provide substantially greater ion elimination efficiency and water recovery[1,6,14]. Furthermore, due to the selectivity of anion and cation transport. Such membrane helps in increasing the capacity storage of carbon electrodes by more than 30 %.[7,9,13] The physical barrier is formed among spacer channels so the scaling fouling sensitive electrodes lead to a reduction in the sensitivity of electrodes .The various benefits of using MCDI over reverse osmosis treatment are as below, The first benefit is that MCDI is not vulnerable to the SiO_2 scale since silica is neutral or acidic pH and hence does not interact with MCDI. As a result, SiO_2 remains in the circulating water and may function as protection or inhibition against corrosion[4,22]. MCDI does not react with the silica in a neutral or acidic medium, so it is inhibited against scale.The important benefit of the proposed method is that higher water recovery can be achieved almost up to 80% which results in water conservation to large extent in cooling towers in thermal power plant. Another benefit is that deionizing a cooling tower's feed water stream reduces the need for prefiltration and antiscalant. The input water will have less tendency of scaling and foul in the system. Another important benefit of using MCDI's less electricity consumption, which will help in saving operation cost. In this paper, we show how to use MCDI at two different cooling tower sites. In one cooling tower, we will be using soft water and in another cooling tower, we will use hard water. The experiment was carried out for one year of each stream and water and energy parameters were recorded with MCDI. The study reflects the amount of water conservation that can be accomplished by employing MCDI by comparing cooling tower operations without MCDI. Further, it was observed that low energy consumption was observed with MCDI cooling towers compared to non-MCDI cooling towers. Also, water saving was observed with MCDI technology.

Tools & Operation procedure

Figure 1 shows the MCDI cell with the Carbon electrodes separated by the spacer. All electrode weights are approx 0.52 g/cm^3 and thickness of 250+/- 50 minute. The ion exchange membrane is placed on top of these carbon electrodes cation and anion exchange membrane are kept on the upper side of the cathode and anode respectively. The thin graphite sheets used as a current collector are connected with electrodes. These graphite sheets act as electrical conductors which allow charges to go into and out of the electrodes. The feed water is allowed to pass through spacer acts as a flow channel between two membrane.The cathode exchange membrane on the cathode's cation-exchange membrane only enables the cation to enter the anode. During the same period, the anode's anion exchange membrane only enables anions to enter the anode.

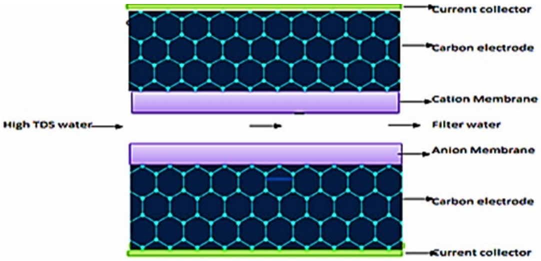

Fig. 1. Block diagram of various components of MCDI Cell

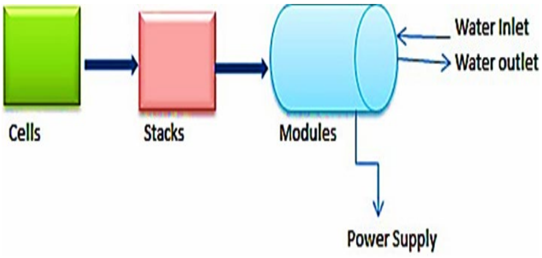

Fig. 2. Block diagram of construction of module cells combine with stacks and stacks further combine to form modules with water inlet and outlet along with power supply

There is a central hole in each unit cell. The shape of unit cells is square, allowing for the outside-in flow of water. A stack is formed by combining unit cells. Every module has a cell area of roughly 6 m^2. A water intake is located on the module's exterior border, allowing water to arrive at the outside of every single cell. At the top center of the module water exit is located and also connected inside each unit cell of the stack. The water will be deionized as there will be a difference in pressure between the inlet and outlet. The water will pass through spacers in unit cells. Each cell's current collector in each module is joined which allows two leads in the module to leave: one exit for all anodes and a second exit for every cathode. All wires in the circuit are connected whose output is limited to +1.2 Volts to avoid undesirable sub-reactions like splitting of water.

The procedure of MCDI is split into two stages. The first process also called deionization, helps in the removal of ions through the input water supply and stores them within the electrodes inside the system. Applying a voltage differential across the cell is the initial step. This helps in migration by creating initial force from the spacer compartment's water to the porous electrode surface via the ion exchange membranes. Split ions are captured at the interface of carbon–water and stored as porous electrodes in double layers. As consequence, ions in the space chamber decrease, and the influent salinated water becomes deionized.

Electrodes must be renewed when once they have been charged with ions. This is done in a second step, which is frequently referred to as regeneration. In the regeneration step, If cell voltage potential difference is reversed, electrodes deposited ions are returned to the spacer compartment area. As a result, the concentrations in the spacer chamber rise, and the concentrate stream is pushed out of the MCDI cell. In the constant current conditions, MCDI was operated, which means throughout filtration and regeneration processes, supply continuously constant current to the unit cell, and absolute charge transportation was equal in both phases. A continuously constant current process enables for consistent removal of ions from the feed stream system during the purification step, when combined with water steady flow in the cell, results in consistent deionized water quality.

Design and operation of a cooling tower

Water inflow of a cooling system, MCDI units installed at twice distinct places. Among them first place is Vadinar factory, where a 650-kW cooling need is met by an evaporative cooling tower (make SPIG). Each year, about 2600 m^3 of municipally treated wastewater is make-up to the CW system to meet the requirement of evaporation loss and blow-down. This system was operated and under observation throughout the year, along with a two-month start-up time to fine-tune the MCDI operation and a ten-month analysis period. To assess water and chemical savings, just the evaluation period was used.

The second place is the factory located in Salaya building, where an evaporative cooling tower (Make Thermax) meets the cooling requirement of 4700kW. Every year, roughly 11,000 cubic meters of hard municipal water is utilized as a cooling system make-up to meet the evaporation loss and blow-down. This system was operated for 180 days, with a 60 days baseline and 120 days of observation Diagram 3 shows a scheme of CT arrangement incorporating MCDI-installed technology. At place 1, soft treated water was used as the makeup of the feed stream, while at place 2 used hard water with SS particles. Prefiltration treatment has been carried out with a bag filter size of 30 microns and a cartridge filter size of 1 micron. On both sides to give protection to the MCDI stack from particles present in water. Two vertical sections for site 1 and four vertical sections for site 2 make up the MCDI used in this study. The deionized effluent is sent to a buffer storage container, while the high TDS concentrated water stream is routed to the sea, using valves. A flow is controlled by a flow regulator which was used to adjust the flow during the deionization and concentrate phases. This system was controlled by programmed with logic (Siemens SIMATIC S9-1800) including valves, flow controllers, and power supply. Various types of chemicals like corrosion inhibitors, scale inhibitors, and biocides were added to the buffer tank to avoid corrosion, biofouling, and scaling. An online conductivity analyzer was installed in the tank inlet to test CT recirculation water conductivity. As soon as detects the threshold limit of conductivity is, a small amount of water is dumped in the blowdown line. The buffer tank was outfitted with level controls to permit the dilution of the recirculation water by MCDI deionized stream, as a result, avoid corrosion and scaling in the cooling tower. In the process that tower water usage surpassed the MCDI deionization capacity, another facility bypass line was installed to make up feed water to reach the buffer vessel directly.

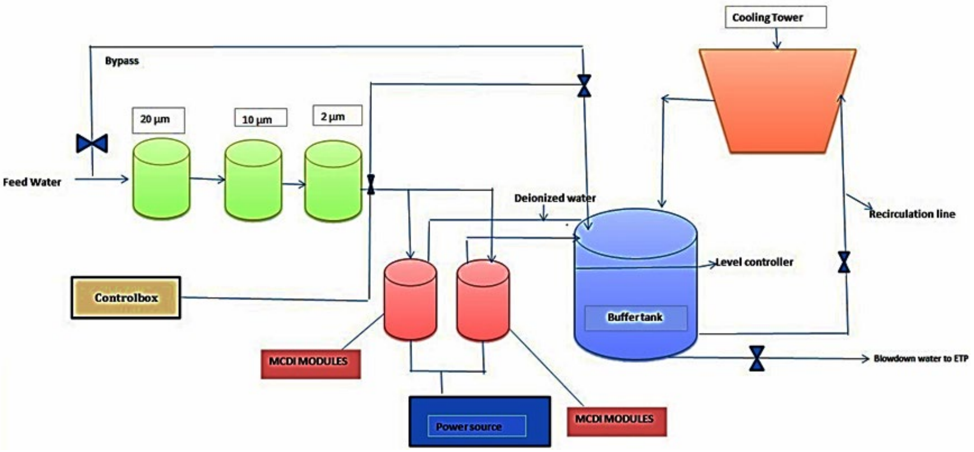

Fig. 3. Schematic figure showing scheme of cooling tower with MCDI cells

Table 1 summarizes the operational differences between different locations 1 and 2. Calcium concentration is controlled by adjusting water recoveries. Table 1 shows that less current will be used when conductivity is less in feed water. Removal of ions is directly relative to current.

Table 1: Comparison of parameters between the two different Location

Parameter	UOM	Location 1	Location 2
Flow in regeneration	L/Min/Module	1.6	1.8
Current in regeneration	A/Module	89	41
TDS removal	%	69%	72%
Water recovered	%	83	80
Flow in deionization	L/Min/Module	6.8	6.8
Current in deionization	A/Module	59	27

During the regeneration step, the regeneration current was increased by 1 Amp. compare to the requirement of current for balancing of charge and to ensure complete electrode discharge. The removal of ions and TDS or conductivity removal is to be compared. And a water test was carried out of makeup to the feed stream and deionized stream. The analysis was performed by using inductively coupled plasma mass spectrometry (ICP-MS) to get the mass concentrations of cation and metals, ion chromatography to analyze concentrations of anions, titration to analyze chemical oxygen demand, and spectrometry to analyze the silica (SiO_2). The concentration of total dissolved solid was calculated from ion group concentrations.

Case analysis

Calculate water requirement, blow down, and save wastewater by using MCDI, actual operation in which MCDI was utilized to treat the ongoing water was compared to the case in which the cooling requirement is the same but without feed, water demonized by MCDI. In the case of MCDI, water quantity is measured in the feed stream using a water meter. Based on Eq. 1a & 1b, the quantity of MCDI concentration stream was got by MCDI's water recovery/saving, which is denoted in the ratio of water quantity in the demonized stream to the feed stream water quantity-1b. After 9 months of assessment, Fig. 4a shows the deionization voltage and current profile during the regeneration cycle of the MCDI at the first site; Fig. 4b shows the deionization conductivity of outlet water and flow during the regeneration cycle. The direction of charge transport is shown by the sign of the current in Fig. 4a; when observing that positive current, it shows that the module is in charging condition, which means it works in deionization mode; when observing that negative current, it shows that the module is in discharging condition, means it works in regeneration mode. Fig. 4a also demonstrates that the current was no longer steady in the last 10 seconds of regeneration, indicating that the power supply's voltage limit had been surpassed. This is happened due to greater currents setting regeneration mode, which causes leads to the failure of the electrodes.

As shown in Fig. 4b, in deionization mode, feed water conductivity lowered from approx. 0.60 mS/cm to roughly 0.18 mS/cm in demonized water, resulting in the removal of conductivity is 70%. And the flow was also lowered to 1.6 L/min during the regeneration process to maximum recovery/

saving, and conductivity got around 2.5 mS/cm. In regeneration, the last couple of seconds i and e. 5 seconds, given positive current and increased flow to get a guarantee. And output water conductivity is also low enough to begin the fresh deionization stage. Calculate water recovery by using equations (1a) and (1b), it got 83 percent. The system was outfitted with a separate sensor of voltage and current to calculate Energy consumption per m^3 of generated water. Compare the determined Energy consumption value of CDI and MCDI with standard literature values. This energy use standardized on reduction in conductivity/TDS of deionized water to get energy consumption during TDS or conductivity reduction in kilo Joule /g, which had been reported in feed water composition report[15–17]. In actual operation, utilized MCDI was to treat ongoing water was compared to the situation where the same cooling demand was observed but without deionized feed water by MCDI. Evaluate water saving by calculating blowdown water and wastewater generation in both methods.

Case base-calculations

Calculate water requirement, blowdown water, and wastewater cost reduction by using MCDI. In real operation, in which MCDI being applied to treat ongoing water was compared to different cases in which the cooling requirement is the same but without deionized input or feed water by MCDI.In the MCDI case, available water quantity has been determined in the feed stream using a water meter. About Equations. 1a &1b, MCDI concentrate stream volume was determined by water recovery/saving, and it is defined as the ratio of deionized stream water volume as VDI to feed stream water volume as VF-1b.

The cooling tower cycles-of-concentration (COC) is defined as the ratio of the threshold value of conductivity or TDS set point for blowdown (BD) and conductivity or TDS of a make-up deionized stream (DI) (2)The BD for site-1 1400 S/cm is the desired set point, whereas the BD for site-2 1020 S/cm is desired set point. DI was measured at both sites using a conductivity meter placed in the deionized stream makeup. Blowdown qty. (VBD) and evaporation qty. VE may be computed from the COC by using Equations. 3& 4. Concerning Equation. Total wastewater quantity (VTW) is the addition of the blowdown quantity VBD and MCDI concentrate quantity VC (5).

RESULT AND DISCUSSION

As shown in Fig. 4a the voltage and current data of the regeneration–deionization process of MCDI at location 1 from 01.01.2021 to 30.8.2021.

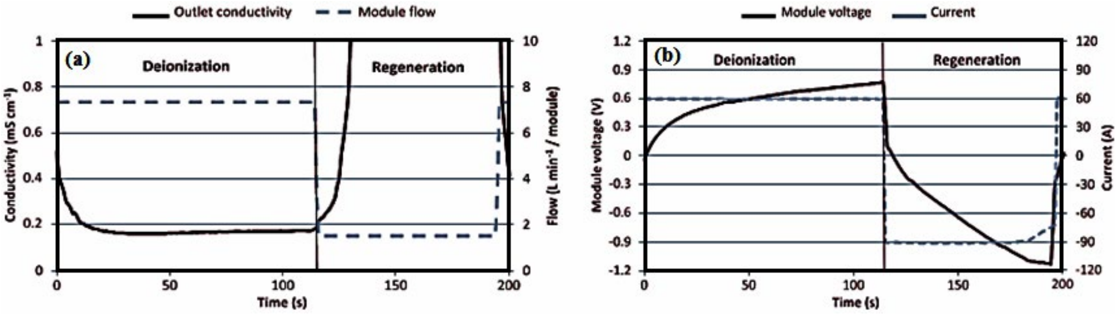

Fig. 4a & 4b. Conductivity change along with time during deionization process

Figure 4b shows the discharge conductivity or TDS and unit water flow in the same process. Fig. 4b shows. The direction of charge transport shown by a current sign Fig. 4a; shows deionization process starts at the current is positive. The regeneration process will take place when the current is negative Fig. 4a also demonstrates that the current was no longer steady in the last 10 seconds of regeneration because the power supply's voltage limit was achieved.

The total waste water quantity will be the sum of MCDI waste water and total blowdown water of system. The quantity of total waste water in abssence of MCDI is same as blowdown water because without MCDI there will be no concentrate present in system. The Cycles of concentration in absence of MCDI will be same as ratio of total blowdown water and maximum conductivity and conductivity of input water, which for Location 1 is 2.1 and for location 2 is near to 2.85.

These are owing to the greater currents applied for the period of regeneration, which results from the electrodes being entirely depleted before the regeneration process is completed. The feed water conductivity is reduced from 0.64 Ms/cm to 0.18 Ms/cm which results in the removal of ions up to 65-70% which is shown in Fig. 4b To get the maximum water recovery during regeneration the flow reduced to 1.5 L/minute. The positive current provided and flow has been increased during the last 5 seconds of regeneration. During the last 6-second process of regeneration guarantee that outlet conductivity is suitably lower before commencing the fresh de-ionization process. Water recovery/saving computed around 83 percent.

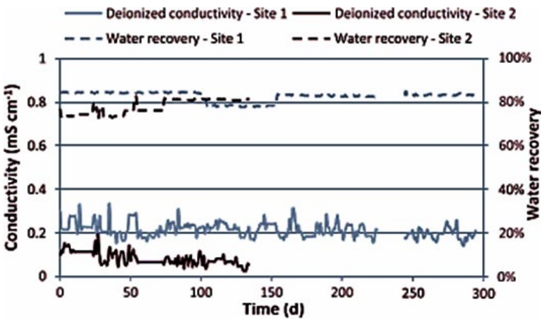

Fig. 5. Water recovery of two different sites with conductivity change along with time

Figure 5 depicts the conductivity of purified water & water recovery gets throughout the assessment period for cooling tower operations with MCDI at both sites. In the study duration, water recovery and deionized conductivity at the first site were rather stable. Water recovery and conductivity removal at the second site were raised by around 5% throughout the assessment period to improve chemicals and water conservation/savings. As per Fig. 6 depicts the accounting combined water usage in evaluation duration when MCDI is utilized, and measures up to the total water consume exclusive of MCDI (6). Fig. 7 depicts the blowdown quantity and combined wastewater quantity in assessment duration, as calculated by Eqs. 3&4, in comparison to total wastewater.

Table 2: The energy and chemical saving of two different location

Parameters	Location 1	Location 2
Water conservation%	29	13
Waste water reduction %	49	33
Energy optimization		
kJ/ g1 TDS reduction	2.7	2.3
kWh/ m3 treated water	0.224	0.107
Chemical Optimization	78	83

Figures 6 and 7 demonstrate that water usage and wastewater discharge for the second site increased significantly after sixty days. It corresponds with the commencement of a hot spell, subsequent in a larger cooling demand. The cooling tower at the first site on the other hand was utilized for industries operation, hence cooling requirement was higher consistently during the year.

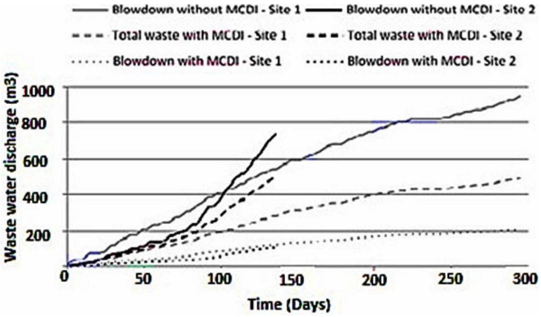

Fig. 6. Waste water discharge along with Time (days) of different Sites

Table 2 summarizes the overall water, chemical, and saving in wastewater for both cooling tower locations for the full assessment duration, as well as the average energy consumption for both sites.The water conservation is more at location 1 than location 2, owing to the use of soft water feeding at the first site, which permits for more recovery of water. As there is low conductivity at the second site significant chemical savings were obtained, resulting achieves high cycles' of concentration in the cooling tower and accordingly blow down water quantity is smaller. Applied voltage and current in the regeneration stage for filtration were used to compute MCDI energy usage, with applied lower currents resulting in reduced energy consumption[11,15].

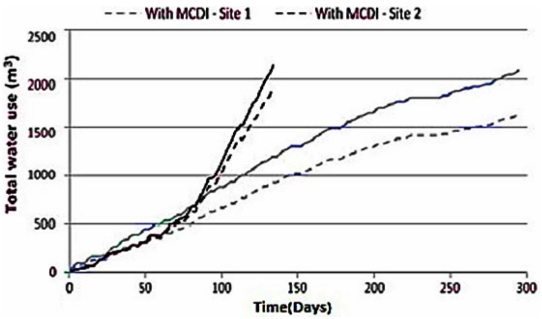

Fig. 7. Total water consumption along with Time at two different sites

Higher currents were employed in regeneration during this study to reduce regeneration time and obtain a higher water output. Whenever just energy consumed in the purification cycle is considered only, the energy consumed is significantly low, with 1.3 kilo Joule g^{-1} TDS reduced for the first site and 1.1 kilo Joule g^{-1} TDS reduced for the second site. This value is equivalent to previously reported TDS reduction levels of 0.9–1.5 kilo Joule g^{-1} [19]. MCDI energy consumption for each quantity of DI water kept around 0.2 to 0.3 kWh/m^3, and it matches well with the energy consumption of 0.88–1.59 kWh/m^3 DI water for the treatment of brackish water by RO[20]. It can be further down by keeping lower regeneration currents and in the regeneration stage, it can utilize recovered energy also[6]. The commercial gains of employing MCDI for CT may be determined by matching acquired water and chemical savings to the capex and operating costs in the financing method, which shows favorable returns on investment of both sites for the owner of the site.As shown in Table 3 comparison of various streams like feed water, deionized water, and the species removed in deionization.

Table 3: Various parameters of feed water and deionized water of two different location

Parameters	Feed water		Deionized water		Removal	
	L1	L2	L1	L2	L1	L2
Bulk parameters						
pH	7.6	8	6.8	7.6	–	–
Conductivity (μS/cm)	640	370	226	129	0.64	0.67
TDS	500	290	176	110	0.66	0.65
Anions (mg/L)						
SO_4^{2-}	112	18	70	10	0.42	0.56
Cl^-	23	36	2	9	56	0.74
NO^-	1.17	1.89	0.5	0.6	0.7	0.76

There were no detectable metals at any locatio. Table 3 reflects that some ions elimination was greater than removal of average TDS/conductivity (highlights in Table 3), demonstrating that these types of ions had better absorption in MCDI. Hence other ions were eliminated to a lower degree. The first and second site locations demonstrated considerable preferential absorption of mono-valent anion while dramatically reducing sulfate uptake. Site two demonstrated preferential bivalent uptake. The silica present in feed water is neutral hence it cannot be removed during operation COD was only eliminated from 22% of the sites in site 1 and at least 29% of the sites in the second site. This is most possibly caused by the removal of hydrophilic chemical molecules with low molecular weight and charge that can pass through the membrane. The reason for selective ion absorption in MCDI has not earlier been defined, yet it is well believed that in the electrode ionization process in absence of membranes (CDI). In CDI ion preferred absorption is governed by charge (z) and the ion's hydrated radius-r_h; small, multi-valent ions are energetic so it is more easily stored in two layers than big, mono-valent ions, as may be inferred from stern goy.

Bivalent cations ie. Ca and Mg give more preference over mono-valent cations in this study, and relatively small ion Ca (r_h=0.412) exhibits favorable uptake versus Mg (r_h=0.428), as well as K (r_h=0.331) vs Na (r_h=0.358). These findings are consistent with the uptake of cation order observed in previous research.

CONCLUSION

Thus from above study it can be concluded at there is water and chemical saving in cooling tower by using MCDI. Chemical saving was around 80% and water saving was 24%. During the experiment no fouling was observed in cooling system hence silica is not taken in MCDI.

ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The author declare that we have no conflict of interest.

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