Performance evaluation of hybrid OMBR-MD using organic and inorganic draw solutions
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ABSTRACT

The performance of two inorganic divalent salts (CaCl₂ and MgCl₂) and two organic salts (CH₃COONa and Mg(CH₃COO)₂) was compared with commonly used NaCl in an osmotic membrane bioreactor (OMBR) integrated with a membrane distillation (MD) system. The system was investigated in terms of salinity buildup, flux stability, draw solution (DS) recovery and contaminants removal efficiency. Results indicated that organic DSs not only lessen the salt accumulation within the bioreactor but also increase the pollutant removal efficiency by improving biological treatment. Of all the draw solutions, NaCl and CaCl₂ produced rapid declines in water flux because of the high salt accumulation in the biotank as compared to other salts. The DCMD system successfully recovered all organic and inorganic draw solute concentrations as per OMBR requirements. Membrane flushing frequency for the MD system followed the order Mg(CH₃COO)₂ > CH₃COONa > CaCl₂ > MgCl₂ > NaCl. More than 90% removal of chemical oxygen demand (COD), NH₄⁺-N, and PO₄³⁻-P was achieved in the permeate for each salt because of the dual barriers of high-retention membranes i.e., forward osmosis and MD.

Key words | draw solutes, flux stability, reverse solute transport, salinity buildup

INTRODUCTION

In the last decade, forward osmosis (FO) membranes have been investigated in membrane bioreactor (MBR) processes for the development of an innovative idea i.e., the osmotic membrane bioreactor (OMBR) to increase dissolved solid rejection, obtain superior effluent quality, minimize power consumption and lower membrane fouling propensity (Achilli et al. 2009). Additionally, osmotic pressure as an alternative for hydraulic force is used in the FO system resulting in reduced and compact biofilm as compared to the biofilm generated by hydraulic pressure (Lay et al. 2010a; Kazner et al. 2014). In spite of these advantages, OMBR also presents some technical challenges such as lack of appropriate draw solution (DS) recovery method, membrane fouling during prolonged filtration runs and salinity buildup in the bioreactor due to reverse salt flux. Salt accumulation within the bioreactor severely affects the bioactivities of microbial flora, as the majority of the functional bacteria are extremely sensitive to high saline stress environment (Luo et al. 2014, 2016). Researchers have applied different approaches to confronting these challenges of salinity buildup within the bioreactor, such as: sludge wastage by optimizing the solids retention time (SRT), removal of supernatant from settled biomass, integration of ultrafiltration (UF) or microfiltration (MF) units with the OMBR to bleed out the extra salt content via the MF/UF membranes, employment of organic DSs instead of inorganic salts, etc. (Wang et al. 2014; Aftab et al. 2015; Luo et al. 2016). Recently, the use of organic DS in FO systems has emerged as a promising approach to reducing the saline stress within the bioreactor because organic ions diffusing into the bioreactor across the semi-permeable membrane can easily be biodegraded by the activated biomass (Bowden et al. 2012; Holloway et al. 2014; Ansari et al. 2015).

Moreover, the maintenance of an osmotic gradient between the feed and DS sides is also considered to be a hurdle for continuous OMBR operation. To date, separation processes such as electrodialysis (ED), reverse osmosis (RO), nanofiltration (NF), UF and membrane distillation (MD) have been evaluated for the recovery of DSs. Regardless of being well-established and having a low energy requirement, UF membranes may not effectively reject the draw solutes because of their large pore size (>10 nm).
(Eltawil et al. 2009). Integration of solar energy with ED may recover the draw solutes economically, but the high cost of ion exchange membranes and electrodes are not economic for the recovery of draw solutes for FO systems. High operative pressures of NF and RO membranes do not favour draw solute recovery. By contrast, MD can be considered as a suitable option, offering notable advantages such as low capital cost, utilization of low-grade heat, high water quality and having lower salinity (Luo et al. 2014). Additionally, the diluted draw solutions can be easily recovered by the MD process as the water flux of the MD membrane is not sufficiently altered by the salt concentration in the feed (Nguyen et al. 2016). Due to these features, recovery through MD membranes is becoming an attractive technology for the various FO applications.

Both FO and MD processes have their own limitations as standalone systems: salinity buildup within the bioreactor and DS or osmotic gradient recovery in the OMBR system, and rapid membrane fouling and wetting issues in the MD process (Husnain et al. 2015). Therefore, the integration of OMBR and MD systems may overcome the hurdles of the separate systems: i.e. OMBR acts as a pre-treatment to prevent the direct fouling of the MD membrane and MD system is utilized for the maintenance of an osmotic gradient on the DS side. Integration not only compensates for the bottlenecks of both the systems, but also facilitates the efficient rejection of pollutants for the production of clean water. In this study, the performance of three divalent inorganic (NaCl, CaCl₂ and MgCl₂) and two organic (CH₃COONa) and (Mg(CH₃COO)₂) draw solutions were investigated in a hybrid OMBR-MD system in terms of flux, salt accumulation, DS recovery and pollutant removal efficiency. The aim of the present research was to investigate the spectrum of flux stability and draw solute recovery across organic and inorganic DSs.

**MATERIALS AND METHODS**

**OMBR and DCMD membrane**

A flat sheet cellulose tri-acetate (CTA) OMBR membrane by Hydration Technology Innovation (HTI, USA) was used in this study. A microporous hydrophobic direct-contact membrane distillation (DCMD) membrane was obtained from Ningbo Changqi Porous Membrane Technology Co. Ltd (China). Porosity, active layer thickness, and average pore size of the DCMD membrane were 70%, 12 μm, and 0.2 μm, respectively.

**OMBR and DCMD hybrid system**

A laboratory-scale schematic of the hybrid OMBR-MD system is shown in Figure 1. The system consists of two membrane modules each for the OMBR and DCMD. The double-sided FO module with a length, width and height of 30, 30 and 1.5 cm, respectively, was used in this study. An OMBR membrane with an effective area of 0.12 m² was sealed on a plate and frame type acrylic module submerged in the bioreactor. For the active growth of microorganisms and membrane scouring, an air pump was used to maintain dissolved oxygen levels of 3–4 mg/L in the bioreactor. Bioreactor conductivity was measured using an inline total dissolved solids (TDS) meter. The level of liquid in the bioreactor was maintained by a peristaltic pump (Cole Parmer, 77200-62, Masterflex, USA) with relay unit (Omron Floatless Level Switch, 61F, Japan). The water flux of the OMBR membrane was measured by weight changes of the draw tank, which was placed on a digital balance (UX6200H, Shimadzu, Japan) connected to a computer. DS circulation from draw tank to the OMBR module was maintained at a cross-flow velocity of 500 mL/min using a peristaltic pump (Cole Parmer, 77200-62, Masterflex, USA).

For recovery of DS and clean water production, the DCMD system was coupled with an OMBR in which the DS tank of the OMBR served as the feed solution (FS) tank of DCMD. The flat sheet DCMD acrylic module consisted of two sides, each side with a length, width, and depth of 10.6, 4.5, and 0.3 cm, respectively, having an effective membrane area of 48 cm². Two peristaltic pumps (Cole Parmer, 77200-62, Masterflex, USA) were used for the circulation of both feed (i.e. DS) and distilled water at a flow rate of 1,000 mL/min in a countercurrent direction through each side of the module. To heat the FS, a stainless-steel heat-exchange coil was submerged in a hot water tank connected to a temperature controller. The inlet and outlet temperatures of the DCMD feed water were measured by two temperature sensors (TPM-900, Sanhng, China). A distillate temperature of 10 °C was controlled by a chiller. To measure...
the inlet and outlet TDS and temperature of permeate water, two inline TDS meters with temperature sensors (Komatsu, Japan) were used. Permeate solution tank was placed on digital balance (UX6200H, Shimadzu, Japan) attached to a computer to measure the water flux.

Feed and draw solution characteristics

Synthetic DS was prepared utilizing two organic and three inorganic salts. Sodium chloride (NaCl), magnesium chloride (MgCl2), and calcium chloride (CaCl2) were used for the inorganic DSs and sodium acetate (CH3COONa) and magnesium acetate (Mg(CH3COO)2) were used for the organic DSs. The DSs were prepared by dissolving a 0.25 M of these salts in distilled water. Nawaz et al. (2013) found that the growth of microbes in OMBR was better supported by divalent salts as compared to monovalent salts. In this study, the mostly widely used divalent salts (MgCl2 and CaCl2) were selected to represent inorganic divalent DSs in addition to NaCl. CH3COONa and Mg(CH3COO)2 were selected as organic draw solutes due to their high biodegradability, lower reverse solute flux and wide use in OMBRs to control salinity (Bowden et al. 2012; Ansari et al. 2015).

A synthetic domestic wastewater was prepared as the FS of the OMBR. Its composition is shown in Table 1.

Operating conditions

In the OMBR-MD system, the FO membrane was submerged in a bioreactor having a 4.5 L working volume, inoculated with activated sludge having a mixed liquor suspended solids (MLSS) concentration of 7–8 g/L from NUST MBR Plant, Islamabad. Before the OMBR was inoculated with activated sludge, the sludge was acclimatized with synthetic wastewater for 2 weeks. Fresh sludge was obtained for each new DS run. The OMBR system was operated under an SRT of 20 days with an initial hydraulic retention time (HRT) in the range of 7–10 hrs for each DS. The OMBR-MD system operation was terminated when the flux of the FO membrane declined to 20% of the initial flux. For the regeneration of the DSs, the DCMD was operated continuously with the OMBR where the initial circulation velocity of the DCMD on the feed side was kept at 1,000 mL/min. Feed temperatures of 70, 65, 70, 80, and 85 °C for the NaCl, MgCl2, CaCl2, CH3COONa, and Mg(CH3COO)2, respectively, were selected based on the water transfer rate requirement of the OMBR. The DCMD water transfer rate was adjusted to match that of the OMBR by changing the circulation velocity and flushing the DCMD membrane with distilled water. The effective temperature difference between the feed and permeate sides of the DCMD were 60, 55, 60, 70, 75 °C for NaCl, MgCl2, CaCl2, CH3COONa, and Mg(CH3COO)2, respectively. When the DS concentration increased, the DCMD circulation velocity was reduced and when the DS concentration decreased, the DCMD membrane was flushed with distilled water to match the water transfer rate of both systems. Membrane flushing was performed using distilled water at a cross-flow velocity of 1,500 mL/min for 1 hour at a temperature of 25 °C. To avoid any pressure difference, the same operating conditions were applied on the permeate side as well. In previous studies, Xie et al. (2014) matched the fluxes of FO and MD by decreasing the permeate temperature of the MD and the flushing the FO membrane. Luo et al. (2016) balanced the water flux of RO membrane with MD by changing the hydraulic pressure of the RO membrane on daily basis.

Analytical methods

Chemical oxygen demand (COD), ammonium-N (NH4-N), and phosphate-P (PO43-P) were measured as per Standard Methods (Rice et al. 2012) to assess treatment performance. Water flux across the OMBR and DCMD membranes was calculated using Equation (1).

\[ J = \frac{\Delta V}{\Delta t \times A} \]  

(1)

where J (L/m²/h or LMH) is the water flux of the OMBR and DCMD membranes, \( \Delta V \) (L) is the change from the initial to the final permeate volumes over time \( \Delta t \) (h), and A (m²) is effective membrane area of the OMBR or the DCMD.

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**Table 1 | Synthetic wastewater composition**

<table>
<thead>
<tr>
<th>Solutes</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (C6H12O6)</td>
<td>308.40</td>
</tr>
<tr>
<td>Ammonium chloride (NH4Cl)</td>
<td>114.60</td>
</tr>
<tr>
<td>Potassium phosphate (KH2PO4)</td>
<td>44.0</td>
</tr>
<tr>
<td>Magnesium sulfate (MgSO4.7H2O)</td>
<td>2.92</td>
</tr>
<tr>
<td>Calcium chloride (CaCl2)</td>
<td>2.92</td>
</tr>
<tr>
<td>Ferric chloride (FeCl3)</td>
<td>0.88</td>
</tr>
<tr>
<td>Manganese chloride (MnCl2.4H2O)</td>
<td>0.60</td>
</tr>
<tr>
<td>Sodium bicarbonate (NaHCO3)</td>
<td>69.71</td>
</tr>
</tbody>
</table>

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**References**

The water transfer rate of the OMBR and DCMD were obtained by multiplying the membrane effective area by the permeate flux.

RESULTS AND DISCUSSION

Water flux of FO membrane

For each DS, Figure 2 shows the water flux of the OMBR system as the function of time. CaCl₂ and NaCl produced the highest initial flux followed by CH₃COONa, MgCl₂ and Mg(CH₃COO)₂. The initial flux trends were influenced by the respective osmotic pressures at the same molar concentration of 0.25 M but were not able to influence the filtration durations as reported in previous studies (Achilli et al. 2010; Ansari et al. 2015). Moreover, due to the high rejection of salt by the DCMD membrane at the end of each run, a minute decrease in DS concentration was observed. The flux decline in the OMBR system was due to either fouling of the membrane or the raised salinity level of bioreactor. An increase in salinity level decreases the osmotic pressure difference between feed and draw solutions, resulting in a rapid flux decline of NaCl and CaCl₂ (Aftab et al. 2015). The filtration run of NaCl was observed to be 12 days in comparison to 16 and 21 days for CaCl₂ and MgCl₂, respectively, at the same molar concentration. At the end of each run, a sticky fouling layer was observed for each inorganic DS, which was due to the increase of soluble microbial products (SMP) as the osmotic pressure increased on feed side (Zhang et al. 2014; Aftab et al. 2015).

On the other hand, the organic DSs (CH₃COONa and Mg(CH₃COO)₂) produced prolonged and stable filtration runs and lower salinity buildup within the bioreactor. At the same molar concentration of 0.25 M, Mg(CH₃COO)₂ showed a prolonged filtration run of 24 days as compared to 19 days for CH₃COONa. The water flux of CH₃COONa declined noticeably, even with less salinity buildup as compared to MgCl₂, due to severe membrane fouling. At the end of the filtration runs of CH₃COONa and Mg(CH₃COO)₂, attached biomass on the membrane surface was observed as the reverse solute flux of organic salts (acetate ions) act as a source of food for the growth of the microbial community, resulting in the formation of biofilm on the surface of the membrane, as reported elsewhere (Ansari et al. 2015; Luo et al. 2016).

Salt accumulation in bio-tank

The reverse transport of the draw solute from the DS side into the bio-tank act was a major source of increase in salinity buildup within the bioreactor. In addition, salt accumulation within the bioreactor also increased due to the high rejection of feed salts by a semi-permeable FO membrane. As the concentration level of TDS in bioreactor increases, the osmotic gradient between the feed and the DS decreases, resulting in a reduced driving force for OMBR operation (Holloway et al. 2014). Figure 3 shows the trend of conductivity in the bioreactor for each filtration run. In comparison with inorganic salts (NaCl, CaCl₂, and MgCl₂), organic salts (CH₃COONa and Mg(CH₃COO)₂) showed significantly less electrical conductivity (mS/cm) within the bioreactor. The conductivity of CH₃COONa and Mg(CH₃COO)₂ increased from 0.8 to

Figure 2 | Flux of OMBR membrane with inorganic and organic DSs.

Figure 3 | Conductivity in the bioreactor with inorganic and organic DSs.
9 mS/cm and 0.7 to 6.8 mS/cm, respectively. This reduced the conductivity of the bioreactor, resulting in a prolonged filtration run due to the smaller decrease in the osmotic pressure gradient as compared to NaCl and CaCl₂ (Figure 2).

In a previous study using an inorganic DS in an OMBR, Aftab et al. (2015) reported that by using NaCl at 0.5 molar concentration, similar trends of rapid flux decline and significant accumulation of salts in the bioreactor were observed. It was found that the bioreactor conductivity increased from 3 to 26 mS/cm in 3 days of filtration run, while a rapid decline in flux was observed with increased salinity. Moreover, similar trends in flux decline and increase in mixed liquor conductivity were also observed by Luo et al. (2015). Lower specific reverse salt diffusion (Js/Jw) of the organic salts (CH₃COONa and Mg(CH₃COO)₂) as compared to the inorganic DSs indicates a lower salinity buildup in the bio-tank due to the lower reverse salt flux of the organic draw solutes (Achilli et al. 2010; Bowden et al. 2012). Inorganic salts with higher ratios of Js/Jw exhibit higher internal concentration polarization (ICP) on the supporting layer of the FO membrane (Hancock & Cath 2009; Achilli et al. 2010), resulting in lower efficiencies of the system in terms of FO flux and decrease in the membrane selectivity. In addition to this, increased salinity buildup and high SMP production with inorganic salts due to the higher ratios of Js/Jw decrease the osmotic gradient between DS and FS (Aftab et al. 2015), resulting in rapid flux drop. Severe salinity buildup observed with CaCl₂ was actually due to its higher specific reverse salute diffusion (Js/Jw) in comparison with the other draw solutions, resulting in the highest salt accumulation in the bio-tank, as reported in previous findings (Achilli et al. 2010; Bowden et al. 2012).

Contaminants removal by OMBR

Accumulation of organics in the bio-tank

The high rejection properties of the FO membrane from the DS side into the bioreactor resulted in the accumulation of pollutants in the bioreactor. Figure 4 shows the rise in COD concentration within the bioreactor with both inorganic and organic draw solutes. In comparison with the organic DSs, the inorganic salts exhibited a higher level of COD accumulation within the bioreactor. The increased COD within the bioreactor reflects the decline in the biodegradation capacity of the microbial consortium. High salinity levels within the bioreactor inhibit the ability of microbial communities to survive (Lay et al. 2010b; Yogalakshmi & Joseph 2010). Salinity buildup not only affects the activity of microbes, it also increases the level of dissolved organic matter (DOM) that can be ascribed to the release of SMP (Yogalakshmi & Joseph 2010; Qiu & Yen-Peng Ting 2013; Luo et al. 2016).

Comparatively less accumulation of COD in the bioreactor was observed with organic salts (CH₃COONa, and Mg(CH₃COO)₂) (Figure 4). The lower reverse transport of organic DSs not only mitigated the challenge of salinity buildup within the bioreactor but also provided extra food as a carbon source to the microbes. These findings were ascribed to the organic nature of the acetate ion (CH₃COO⁻) resulting in the lower accumulation of organic content within the bioreactor (Luo et al. 2016). The ability of the organic DSs to control osmotic pressure along with their readily degradable nature reduced the osmotic stress on the FS and enhanced the growth of microbes (Oh et al. 2008; Ansari et al. 2015).

NH₄⁺-N accumulation in the bio-tank

Figure 5 shows the NH₄⁺-N accumulation within the bioreactor for each DS at the molar concentration of 0.25M. Nitrifiers, required for nitrification, are slow-growing microbes and very sensitive to the environment (COD, salinity, pH, and temperature) (Lay et al. 2010b). It has also been reported that poor nitrification results from high saline stress environment. The observed accumulation of NH₄⁺-N was due to the increase in salinity within the bioreactor for each inorganic DS (Figure 5). Qiu & Ting (2013) also reported that increased salinity inhibits the
bacterial activity of ammonium-oxidizing bacteria (AOBs). For both organic DSs, the NH$_4^+$-N concentration within the bioreactor continuously declined throughout the runs because of increased biodegradation. As already reported, acetate ions transported through the FO membrane are readily degradable and serve as a source of food for the growth of microbes, resulting in the increased rate of NH$_4^+$-N removal (Ansari et al. 2015; Luo et al. 2016).

PO$_4^{3-}$-P accumulation in the bio-tank

The accumulation of PO$_4^{3-}$-P with five different draw solutions at the same molar concentration is shown in Figure 6. For each DS, the accumulation of PO$_4^{3-}$-P was observed within the bio-tank due to the high rejection characteristics of the FO membrane. As compared to inorganic DSs, organic DSs exhibited lower accumulation of PO$_4^{3-}$-P. With both organic draw solutes, the PO$_4^{3-}$-P concentration within the bioreactor rose to 20 mg/L, having average influent PO$_4^{3-}$-P concentration of approximate 10 mg/L. This was due to effective rejection of PO$_4^{3-}$-P by the FO membrane due to the negatively charged and larger hydrated diameter of the ortho-phosphate ion (Luo et al. 2015, 2016). In addition, the organic DSs exhibited lower accumulation of PO$_4^{3-}$-P due to the increase in microbial growth and higher consumption of PO$_4^{3-}$-P by phosphorus accumulating organisms (PAOs) as reported by Aftab et al. (2015). In case of inorganic salts, salinity buildup within the bioreactor reduces the activity of PAOs due to increasing osmotic stress. Performance of PAOs is also adversely affected by the increased concentration of chloride ions (Cl$^-$) (Lay et al. 2010b; Bassin et al. 2011). Therefore, the increased concentration of phosphate-P with inorganic salts within the bio-tank was actually due to the high saline stress and consequently poor performance of the PAOs. At the end of the filtration run of CaCl$_2$, PO$_4^{3-}$-P accumulation increased to 37 mg/L and similar increasing trends were also observed with NaCl and MgCl$_2$.

Overall treatment performance of OMBR and DCMD hybrid system

The DCMD process successfully recovered the OMBR DS and the OMBR-MD hybrid system produced high-quality product water. The DCMD membrane almost completely removed the salts and contaminants even those that passed through the FO membrane in minute amounts. As shown in Table 2, COD removal of approximately 91–95% was achieved with the inorganic draw solute. About 97–99% COD removal was observed with the organic DSs because of increased biodegradation within the bio-tank. The small amounts of NH$_4^+$-N that passed through the FO membrane, in the case of the inorganic salts due to decreased nitrification, were subsequently rejected by the MD membrane. The overall rejection of NH$_4^+$-N was 90–94% for the inorganic DSs and about 99% for the organic DSs. Due to the dual (FO-MD) membrane retention, PO$_4^{3-}$-P removal for each DS was observed to be more than 99% (Table 2). The OMBR-MD hybrid system permeate contains almost negligible amounts of COD, NH$_4^+$-N, PO$_4^{3-}$-P, and TDS, which makes it an attractive system for the recovery of draw solutes and the production of good-quality reclaimed water.
Water transfer rate of OMBR-MD hybrid system

The DS concentration is the main driving force for extracting clean water across the semi-permeable FO membrane. With the passage of time the DS concentration was diluted and DCMD recovery was optimized accordingly on a trial-and-error basis. As discussed earlier, to maintain a constant concentration of DS, it was necessary to match the water transfer rate of both systems (OMBR and DCMD) by adjusting the circulation velocity or flushing of the MD membrane with distilled water. Figure 7 shows the water transfer rate through the OMBR and DCMD membranes using inorganic and organic DSs. The initial DCMD fluxes were 92, 95, 82, 91, and 100 LMH for Mg(CH₃COO)₂, CH₃COONa, MgCl₂, CaCl₂, and NaCl, respectively.

The flux of the OMBR and DCMD system declined with the passage of time (Figure 7). NaCl shows better performance in recovery by DCMD as compared to the other organic and inorganic salts throughout the filtration run as it did not require any membrane flushing. By contrast, the organic salt Mg(CH₃COO)₂ required the DCMD membrane to be flushed four times. Decline in the MD water transfer rate depends on the viscosity and density of the DS, the concentration of the DS, the feed and permeate temperatures and the circulation velocity (Ramezanianpour & Sivakumar 2014). More flushing of the DCMD membrane with Mg(CH₃COO)₂ was due to running at a high feed water temperature to obtain a high flux, which resulted in the rapid flux decline of the DCMD. Salt concentration was another reason for the rapid flux decline of Mg(CH₃COO)₂ as the flux decline rate increased with increasing salinity. At the same molar concentration, Mg(CH₃COO)₂ exhibited the highest salinity of the salts. For all the other salts, similar trends of decline in the water transfer rate were observed bearing in mind the above-mentioned important factors influencing MD flux. Frequency of DCMD membrane flushing followed the order Mg(CH₃COO)₂ > CH₃COONa > CaCl₂ > MgCl₂ > NaCl. Membrane flushing with distilled water restored more than 87% of the initial MD flux or water transfer rate by mitigating reversible fouling due to deposited salts. The DCMD system successfully recovered the DS as per OMBR requirements and the concentration of DS was relatively stable during each of the filtration runs.

CONCLUSIONS

The results of this study indicate that organic DSs (CH₃COONa and Mg(CH₃COO)₂) show less transport of salts...
Figure 7 | Water transfer rate of OMBR-MD hybrid system.
from the DS tank to the bio-tank as compared to inorganic DSs (NaCl, MgCl₂ and CaCl₂). Increased biodegradation with the organic DSs was observed because of reverse transport of acetate ions within the bio-tank. Both magnesium salts (MgCl₂ and Mg(CH₃COO)₂) at same molar concentration displayed stabilized and prolonged filtration runs. On the other hand, NaCl and CaCl₂ produced high initial water fluxes but with rapid flux declined at the same molar concentrations. Chloride-based salts increased the salinity within the bio-tank, resulting in decreased removal efficiency of pollutants through biological processes. Accumulation of chloride ions increased the PO₄³⁻-P and NH₄⁺-N concentration within the bioreactor. More frequent flushing of the MD membrane was necessary for organic salts as compared to inorganic DSs. As per OMBR requirements, the DCMD system successfully recovered both inorganic and organic DSs. Considering all DSs investigated in this study, Mg(CH₃COO)₂ can be recommended as the most suitable DS as it produces a significantly low reverse solute transport and salinity buildup, stable flux, prolonged filtration run, better effluent quality and low microbial toxicity.

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