The impact of draw solution type on the phosphate recovery from municipal wastewater using forward osmosis

Mehmet Daghan Erden[1], Ozlem Ozcan[2], Nuray Ates[1], Nigmet Uzal[3]*

[1]Dept. Environmental Engineering, Erciyes University, 38280, Kayseri, Turkey
[2]Dept. of Materials Science and Mechanical Engineering, Abdullah Gul University, Kayseri, 38080, Turkey
[3*]Dept. of Civil Engineering, Abdullah Gul University, Kayseri, 38080, Turkey
Keywords: forward osmosis, phosphate recovery, sodium chloride, sodium acetate, magnesium chloride
Presenting author email: ozlem.ozcan@agu.edu.tr

As the world's population continues to rise, consequently the demand increase for chemical fertilizers to ensure food security. The essential ingredient in fertilizer, phosphorus, occurs in limited quantities on the earth (Nancharaiah et al., 2016). The research on wastewater treatment has brought a new perspective to the environmental sustainability of natural resources with the recovery of nutrients in the wastewater, going beyond the concept of removal (Gao et al., 2018). The FO process attracts attention and finds application in nutrient and organic matter recovery owing to its low energy consumption and organic fouling tendency (Cath et al., 2006; Kim et al., 2014; Lee et al., 2010). On the other hand, there is a lack of knowledge regarding the efficiency of FO to maximize levels of phosphorous for the purpose of nutrient recovery from wastewater that is already highly diluted, such as treated municipal wastewater. Currently, it is desirable to do research on the parameters that influence FO performance on concentrating nutrients in order to enhance the efficacy of FO in commercial applications. Meanwhile, research into the factors that impact FO performance in concentrating nutrients is needed with the goal of enhancing FO's performance in large-scale applications. In this study, FO tests were performed using NaCl, NaOAc, and $MgCl_2$ draw solutions at 0.5, 1, and 2 M concentrations and a recovery rate of 60% to assess the effect of draw solution type and concentration for the recovery of phosphate from treated (physical + anaerobic treatment) municipal wastewater. The effect of recovery rate on FO process using the 2 M of $MgCl_2$ draw solution was also investigated.

The FO experiments were conducted using three different draw solutions (NaCl, NaOAc, and $MgCl_2$) at three different concentrations (0.5, 1, and 2 M) and 60% recovery rate. 2 M $MgCl_2$ draw solution was also tested at 70% and 80% recovery rate. A laboratory-scale FO system with a 60 cm^2 active membrane area was used. The volumes of the feed tank and draw solution tank were 1 and 2 L, respectively. Flat sheet cellulose triacetate (CTA) membrane (Sterlictech, USA) was used in FO tests. The temperature was kept constant (25±3ºC) during the experiments. The flux and reverse salt flux (RSF) were calculated by monitoring the feed conductivity and draw side water input throughout the experiment. The surface chemistry of the membranes was analyzed using attenuated total reflection - Fourier transform infrared (ATR-FTIR) spectroscopy by collecting spectra between 4000-400 cm^{-1} in Thermo Nicolet Avatar 370 instrument. The surface morphology of membranes was evaluated using scanning electron microscopy (SEM) in Zeiss Leo 440 instrument.

In FO tests, the initial feed and concentrated feed samples were characterized, and the results are presented in Table 2. While the PO_4^{3-} concentrations of feed was 12.5±2.6 mg/L, the concentrations of the concentrated feed samples ranged from 21.7±0.1 to 31.8±2.6 mg/L. The highest PO_4^{3-} concentration of 31.8±2.6 mg/L was obtained in FO tests for the concentration of the 2 M $MgCl_2$ draw solution. The feed samples had an initial conductivity value of 1.67±0.16 mS/cm, the highest conductivity (4.92±0.32 mS/cm) was found in the concentrated feed sample obtained in the FO tests performed with 0.5 M NaCl. Due to permeation of water from the feed side, the concentration of draw solution declines, while the concentration of feed side increases due to transfer of salt from draw solution (Bamaga et al., 2009). Although the recovery rate was 60% for each test, Na^+ concentrations ranged from 376±13 to 600±50 mg/L for NaCl and NaOAc draw solutions. This difference could be attributed to each draw solution having a different RSF propensity (Ansari et al., 2018; Kahrizi et al., 2020). When comparing the concentrations of Na^+, Mg^{2+}, and Cl^-, it was found that the highest concentrations of Na^+ (600±50) and Cl^- (691±269) were reached in the tests performed using 0.5 M NaOAc and 0.5 M $MgCl_2$ draw solutions, respectively. However, the highest concentration of Mg^{2+} was reached in the tests performed with 2M $MgCl_2$ draw solution. It is known that there is an increase in Na^+, Mg^{2+}, and Cl^- concentrations not only because of the concentration of the wastewater, but also because of the RSF (Eddouibi et al., 2021). However, despite the fact that RSF is seen as a limitation of FO processes, the increase in Mg^{2+} concentration in the concentrated feed samples will provide an advantage in reducing the cost of Mg^{2+} addition in the chemical struvite precipitation process with the goal of nutrient recovery (Devia et al., 2015).

Table 1. Characterization of feed and concentrated feed samples

Sample	pH	Conductivity (mS/cm)	COD (mg/L)	PO_4^{3-} (mg/L)	Cl^- (mg/L)	Mg^{2+} (mg/L)	Na^+ (mg/L)
Feed	7.9±0.3	1.67±0.16	59.0±8.8	12.5±2.6	168±29	15±3	150±13
0.5 M NaCl	7.8±0.2	4.92±0.32	184.7±4.7	21.7±0.1	547±28	34±3	466± 14
1 M NaCl	8.0±0.1	4.54±0.07	148.8±5.9	26.9±0.6	470±3	34±7	474±16
2 M NaCl	8.0±0.2	4.82±0.29	168.0±2.4	26.5±2.3	605±44	41±17	512± 151
0.5 M NaOAc	8.1±0.4	4.92±0.01	262.2±1.8	21.2±3.5	589±240	43±7	600±50
1 M NaOAc	8.2±0.0	3.71±0.10	243.0±47.1	22.4±2.0	478±48	35±1	376±13
2 M NaOAc	8.1±0.1	3.61±0.12	144.7±23.6	28.8±3.3	451±28	96±0	500±29
0.5 M $MgCl_2$	7.9±0.1	4.89±0.02	268.0±9.4	29.2±6.6	691±269	91±10	419±54
1 M $MgCl_2$	8.1±0.2	3.65±0.21	119.7±0.0	28.6±0.2	518±31	69±8	390±36
2 M $MgCl_2$	8.0±0.2	3.76±0.00	242.2±100.2	31.8±2.6	508±13	115±8	482±75

The performance of the FO process for PO_4^{3-} recovery from treated municipal wastewater was tested in this study using NaCl, NaOAc, and $MgCl_2$ draw solutions at 0.5, 1, and 2 M concentrations and at 60% recovery rate. The highest PO_4^{3-} concentration of 31.8±2.6 mg/L was obtained in FO tests at the concentration of the 2 M $MgCl_2$ draw solution at 60% recovery rate. In order to assess the effect of the recovery rate on the performance of the FO process, FO tests were conducted using 2 M $MgCl_2$ draw solution at 60%, 70%, and 80% recovery rates. The RSF nearly doubled when the recovery rate was increased from 60% to 80%. FO has a high potential for the recovery of PO_4^{3-} from treated municipal wastewater However, further investigations are required for the effective management of the diluted draw solution.

Acknowledgments

The authors gratefully acknowledge the Scientific and Technological Research Council of Turkey for the financial support (Project No: 119Y134) and Scientific Research Foundation of Erciyes University (Project No: FYL-2022-11861).

References

Ansari, A. J., Hai, F. I., Price, W. E., Ngo, H. H., Guo, W., & Nghiem, L. D. (2018). Assessing the integration of forward osmosis and anaerobic digestion for simultaneous wastewater treatment and resource recovery. Bioresource Technology, 260, 221-226. https://doi.org/https://doi.org/10.1016/j.biortech.2018.03.120

Cath, T. Y., Childress, A. E., & Elimelech, M. (2006). Forward osmosis: principles, applications, and recent developments. Journal of Membrane Science, 281(1-2), 70-87.

Gao, Y., Liang, B., Chen, H., & Yin, P. (2018). An experimental study on the recovery of potassium (K) and phosphorous (P) from synthetic urine by crystallization of magnesium potassium phosphate. Chemical Engineering Journal, 337, 19-29.

Kahrizi, M., Lin, J., Ji, G., Kong, L., Song, C., Dumée, L. F., Sahebi, S., & Zhao, S. (2020). Relating forward water and reverse salt fluxes to membrane porosity and tortuosity in forward osmosis: CFD modelling. Separation and Purification Technology, 241, 116727. https://doi.org/https://doi.org/10.1016/j.seppur.2020.116727

Kim, Y., Elimelech, M., Shon, H. K., & Hong, S. (2014). Combined organic and colloidal fouling in forward osmosis: Fouling reversibility and the role of applied pressure. Journal of Membrane Science, 460, 206-212.

Lee, S., Boo, C., Elimelech, M., & Hong, S. (2010). Comparison of fouling behavior in forward osmosis (FO) and reverse osmosis (RO). Journal of Membrane Science, 365(1-2), 34-39.

Nancharaiah, Y. V., Venkata Mohan, S., & Lens, P. N. L. (2016). Recent advances in nutrient removal and recovery in biological and bioelectrochemical systems. Bioresour Technol, 215, 173-185. https://doi.org/10.1016/j.biortech.2016.03.129