Assessment of Membrane Fouling Behavior of Nanofiltration and Membrane Distillation for Water Reuse

長崎大学大学院工学研究科
Ngo Thi Tra My

Dissolved organics and trace organic compounds (TOrCs) have been recently found in treated effluent of municipal wastewater treatment plants and recipient waters. This can pose a serious threat to the safeness of reusing water due to the insufficiency of the conventional treatment train against these emerging pollutants. Although membrane-based treatment becomes an attractive option to address contaminated water, membrane fouling remains a major challenge for the sustainable operation of wastewater treatment as it increases the operating cost and shortens the membrane lifetime. This research aimed to establish a membrane selection strategy with different wastewater sources for removing contaminants and minimizing membrane fouling. The direct treatment of secondary wastewater effluent using nanofiltration (NF) membranes was applied for non-potable water reuse while reverse osmosis (RO) and membrane distillation (MD) membranes were used in the treatment of RO concentrate containing high concentrations of salts and organics for potable purposes.

For the NF membrane, a submerged membrane module was adopted at low permeate flux (3 L/m^2h) for alleviating membrane fouling. The separation performance of the direct NF system was assessed by periodically measuring the color, turbidity, UV light absorbance at the wavelength of 254 nm (E_{254}), and total organic carbon (TOC) of the NF feed and permeate. During a 48-d test, direct NF treatment of secondary wastewater effluent resulted in a negligible membrane fouling with the transmembrane pressure increase of only 3 kPa. The fouling speed is far less than the case with a typical permeate flux of 40 L/m^2h (an 18 % permeability drop within the first 4 h), which can require chemical cleaning every few hours. The substances deposited on the membrane surface were readily removed by a polyurethane sponge, which fully recovered the membrane permeability. The cake layer on the membrane surface is the major source of the increased hydraulic resistance. The direct NF treatment stably achieved high removal of organics during the test period with the rejection of color, E_{254}, and TOC at over 93, 84, and 67%, respectively. The excitation-emission matrix fluorescence spectra showed that direct NF treatment considerably reduced the intensity of humic acid-like substances. This study demonstrated the efficacy of the direct nanofiltration treatment using a submerged NF module for achieving a stable operation and producing high-quality recycled water.

The membrane fouling propensity and water quality were compared during the treatment of the reverse osmosis (RO) concentrate by membrane distillation (MD) and RO membranes at a permeate flux of 25 L/m^{2}h. Increasing overall water recovery from 85% to 98% did not significantly reduce the permeate flux (~4%) for MD treatment. However, the considerable increase in transmembrane pressure in only 1.5 h indicates that the treatment of the RO concentrate by RO allowed only 88% of overall water recovery. A reduction in pure water permeability of up to 73% was found after the treatment by RO while MD treatment did not reduce the permeance. This indicates that membrane fouling might occur for the RO membrane. The significant formation of the foulant layer on the membrane surface of the RO membrane was also found. In addition, the MD membrane shows superior retention of almost all the ions and TOrCs. Electrical conductivity rejection was very high (99.8%) for MD, but the treatment led to high permeation of trace organic compounds with high volatility, particularly *N*-nitrosodimethylamine. Post-treatment (e.g., advanced oxidation) after reverse osmosis and membrane distillation may be needed to comply with the *N*-nitrosodimethylamine regulations. This study suggests that MD will be a more feasible choice than RO membrane for increasing water recovery in wastewater treatment. A considerably higher energy requirement in MD highlights the necessity of abundant waste heat or renewable energy sources to enable the applicability of MD treatment.

In general, this doctoral dissertation addresses membrane fouling in advanced water treatment processes as well as ensures treated water quality for potable or non-potable water reuse. The results demonstrate the efficacy of the direct NF treatment using a submerged NF membrane module and the feasibility of MD in RO concentrate treatment for achieving a stable operation and producing high-quality recycled water. Further pilot-scale studies may be conducted to enhance the permeate flux and to minimize the energy consumption for potable or non-potable water reuse. This can be achieved by improving membrane module design in NF and membrane properties in MD.