Recovery of Water and Cleaning Agents from Clean-In-Place (CIP) wastewater using Nanofiltration (NF)-Forward Osmosis (FO)-Direct Contact Membrane Distillation (DCMD): Effects of flow temperature and flow rate

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The recovery of the cleaning agents from Clean-in-Place (CIP) wastewater provides the opportunity to reduce the environmental/economic costs caused by the cleaning operation. The present study proposed Nanofiltration (NF) – Forward Osmosis (FO) – Direct Contact Membrane Distillation (DCMD) to recover the cleaning agents while reclaiming freshwater from the model CIP wastewater. As prefiltration steps, NF was proposed to remove organic residues from the CIP wastewater. After 4 kD and 200 Da NF, the lactose was reduced to a non-detectable level and protein contents were removed by 94%. The permeate from NF prefiltration was further managed by the integrated FO-DCMD. The effects of temperature and flow rate on FO and DCMD were investigated. As the flow rate changed from 500 ml/min to 1500 ml/min, a higher level of water flux could be accomplished for both FO and DCMD. The higher temperature of feed and draw solution was desired to generate a high magnitude of water flux for FO, but the larger temperature gradient between feed and permeate stream was preferred for DCMD. The performances of FO and DCMD were predicted by theoretical models and compared with experimental results. The theoretical models provided close agreement with experimental results. However, the prediction for NF permeates was less accurate due to difficulty in exact estimation for flow characteristics such as viscosity or diffusion rate. During continual concentrating of the NF permeate, the prediction of FO using the theoretical model was not accurate due to fouling formation onto membrane surface that could be attributed to high-temperature operation in feed and draw solution stream. However, the FO-DCMD could accomplish the recovery of high quality water without salts contents. In addition, the cleaning efficacy of the cleaning agents recovered by NF-FO-DCMD was proven to be comparable to the fresh one by a Quartz Crystal Microbalance with Dissipation monitoring (QCM-D).