Membrane-based technologies for the production of high-quality water from contaminated sources: from lab experiments to full-scale system design

Summary

The increasing demand of freshwater worldwide draws research efforts toward the implementation of innovative system processes able to extract high-quality water from contaminated/unconventional water sources. To this purpose, promising results may be achieved by the employment of membrane-based separation technologies, which can help improving the management of water and wastewater streams and a more sustainable human-related water cycle. Within this broad topic, this manuscript presents two case studies in which innovative membrane filtration systems are employed for the recovery of high-quality water from contaminated sources. A methodological approach is presented, where membrane-based solutions are analysed “from lab to full scale” design. In-depth studies of the parameters affecting membrane process performance is first investigated through lab experiments. Consequently, the results obtained in the lab are used to implement and/or evaluate the performance at larger scale, also through system-scale modelling, with the aim to identify the best operating conditions for the final proposal of full-scale designs.

As a first case study, nanofiltration is discussed as a potential technology to produce drinking water from chromium contaminated sources, and sources contaminated by heavy metals in general. Chromium removal is concerning because a new stringent limit was recently adopted in many EU countries. First, three of the most widely used commercial NF membranes are investigated at the lab scale. Overall, laboratory results suggest that tighter NF membranes should be adopted when filtering chromium contaminated waters with significant ions concentration, and in particular divalent cations. Loose NF membranes may instead guarantee higher productivity and adequate Cr rejection in waters with lower salinity or hardness. The influence of the presence of oxidizing agents on membrane

performances and their achievable lifetime is also investigated. Promising results are obtained by filtering real well water samples of different chemical compositions, suggesting that nanofiltration is an effective process to extract safe drinking water from chromium-contaminated sources. Based on these results, pilot experiments are discussed with a pilot installed *in situ*. The denser membranes consistently reject chromium to achieve the desired values in the permeate stream. Finally, a design of a full-scale plant is proposed to treat the contaminated well water, together with the relative economic and environmental assessments. Guidelines are also presented to perform similar analysis and to help with the choice of the most appropriate nanofiltration membrane, depending on the specifics of water chemistry.

The second case study evaluates the feasibility of a forward osmosis – nanofiltration system to extract high-quality water from brackish groundwater and from wastewater. Through lab experiments, magnesium chloride and sodium sulfate are identified as the most promising draw solutes for this application. High-recovery tests suggest that a feasible recovery larger than 60% may be achieved in the coupled technology by filtering these feed solutions. The diluted draw solutions can be completely regenerated through NF membranes, extracting, at the same time, high-quality water on the permeate side, suitable for beneficial reuse.

An in-depth analysis of fouling phenomena shows that the loss in membrane productivity can be partially recovered through mild physical cleaning, suggesting that fouling would not significantly affect the performance of the system. The higher performance obtained by filtering the real wastewater compared to the brackish water sample suggests that the coupled technology is especially promising for the treatment of water matrices with low salinity and high organic contents. From these results, a system-scale modelling is developed to evaluate the influence of different process parameters, in the case of the FO-NF system applied for the treatment of wastewater. Finally, the design of the full-scale FO-NF plant is presented. Simulations show that the overall system can achieve up to 85% water recovery using Na_2SO_4 or $MgCl_2$ as the draw solute. However, periodical change of the draw solutions should be accounted for.

Overall, the methodological approach presented in this thesis may represent a valuable method to evaluate various membrane-based treatment solutions and their potential full-scale applications.