Leadership in Sustainable Infrastructure
Leadership en Infrastructures Durables

Case Study

Vancouver, Canada
May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

OPTIMIZATION OF SOLAR POWERED REVERSE OSMOSIS WATER TREATMENT SYSTEMS

Freire-Gormaly, M.[1, 3] and Bilton, A.[2]
[1,2] University of Toronto, Canada
3 mfreire@mie.utoronto.ca

1 Introduction

Over 663 million people lack access to improved drinking water and its associated health benefits (WHO 2015). These people rely on seasonally available water sources (cisterns, boreholes, and wells) that are often contaminated with chemicals and bacteria (WHO 2015). These remote communities also have limited access to electricity. The high environmental impact and fuel cost have limited diesel power's use for water treatment. Due to the relatively high levels of solar irradiance in many remote communities, photovoltaic reverse osmosis (PVRO) systems (Bilton 2013) are a promising option for these locations.

2 Project Overview

A community-scale PVRO system was installed through a joint-collaborative project between MIT, W.K. Kellogg Foundation, and PVPure in La Mancalona, Mexico in 2013. The community needed clean drinking water from a brackish (high saline and high mineral content well). The project scope required one cubic meter of water per day for the community and the water cost should be below the alternative supplies (purchased off a water truck). To improve the design tool for future PVRO installations, membrane fouling needed to be considered to ensure more robust and long-lasting systems.

3 Innovation

The innovation of the PVRO system was the use of minimal battery storage. Instead, the system operated only when the solar resources were sufficient and the end-product, clean drinking water, was stored in an inexpensive water tank. As well, the system was configured using an optimal design algorithm to select the system components (e.g. pumps, filters, and solar panel size) to maximize the water production. Industrial practice is to operate RO continuously since intermittent operation is thought to cause increased membrane fouling (Poovanaesvaran et al. 2011). Existing PVRO systems have not been designed taking into consideration membrane fouling. The goal of this work is to develop an innovative, automated design tool capable of considering the uncertainty in membrane fouling to recommend a cost-optimal PVRO system design. A preliminary study has shown the distinction between intermittently operated reverse osmosis systems compared to continuously operated systems at the lab-scale (Freire-Gormaly and Bilton 2017). The work here uses experimentally derived membrane fouling characteristics for different operating conditions (with anti-scalant and with or without rinsing of the membranes using 5L of clean water before shutting down the system) observed during intermittent operation. These correlations were used for the cost optimal design of operating conditions for PVRO systems that are robust to membrane fouling.

4 Lessons Learned

One of the key lessons learned is the trade-off between the cost of anti-scalant chemical usage and clean water rinsing can be quantified using optimization to determine the best operating conditions for a PVRO system. The optimization was performed using a genetic algorithm with membrane replacement time, type of anti-scalant used (anti-scalant A or anti-scalant B), and existence of a permeate rinse as design variables. Rinses were assumed to be performed with 5L of clean water produced by the system. Since the system is capable of producing approximately 1000L of water, it was selected as a sufficient amount to flush the groundwater out of the membrane housing, and piping. The membranes then sit in stagnant water with a very low mineral content.

The optimization uses a simulation model based on experimental measurements to estimate water production for different operating conditions. Two representative days of operation with anti-scalant usage and rinsing prior to shut-down (Figure 1a) shows the increased permeability at the start of each day due to flushing of the membrane. The 16 hours of shut-down are not shown. The optimization was performed using an hourly simulation over 5 years which determines the costs of the two anti-scalants ($/lb), and the cost of membrane replacement, and water cost. The operating costs were determined based on the total volume of water produced, the total mass of anti-scalants and their associated costs. The optimal system design used anti-scalant B with rinsing and membrane replacement every 2.6 years. The operating cost of this operating condition is $0.61/m^3. The operating cost exponentially decreases to a minimum cost of $0.61/m^3 at 2.6 years for the case of anti-scalant B with rinsing for different membrane replacement times (Figure 1b). Future PVRO systems can use this approach to select the appropriate anti-scalant, clean water rinsing and time to replace the membranes.

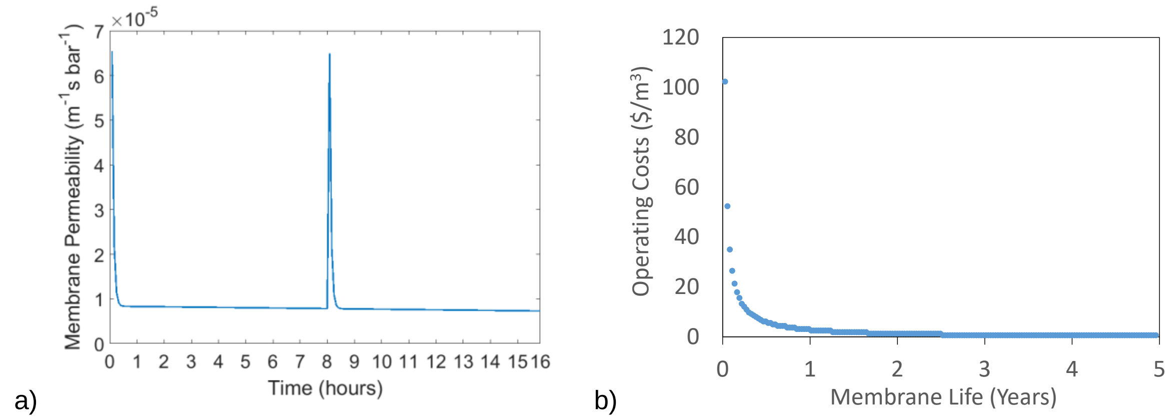

Figure 1: a) Two days of operation with increased permeability after 16 hours of shutdown. b) Operating cost as a function of membrane life for the case of anti-scalant B and rinsing.

Acknowledgements

The authors thank Prof. R.C. Andrews for his feedback on the experiments. The authors also thank research students Youngmok Ko and Francis Cruz. The financial support of MIE at UofT, OGS, Hatch and the NSERC Scholarships are also greatly appreciated.

References

Bilton, A. 2013. "A Modular Design Architecture for Application to Community-Scale Photovoltaic-Powered Reverse Osmosis Systems." PhD Thesis, Massachusetts Institute of Technology.

Freire-Gormaly, M, and Bilton, A. 2017. "An Experimental System for Characterization of Membrane Fouling of Solar Photovoltaic Reverse Osmosis Systems under Intermittent Operation." *Desalination and Water Treatment*.

Poovanaesvaran, P., M.A. Alghoul, K. Sopian, N. Amin, M.I. Fadhel, and M. Yahya. 2011. "Design

Aspects of Small-Scale Photovoltaic Brackish Water Reverse Osmosis (PV-BWRO) System." *Desalination and Water Treatment* 27 (1–3): 210–23. doi:10.5004/dwt.2011.1824.

World Health Organization and UNICEF Joint Monitoring Programme (JMP). 2015 Progress on Drinking Water and Sanitation, 2015 Update and MDG Assessment.