Passive Membranes for Drinking Water Treatment in Small and Remote Communities

Khadem N., Oka P. and *Bérubé P.R.

Department of Civil Engineering, University of British Columbia, 6250 Applied Science Ln, Vancouver BC, V6T1Z4, Canada. * Corresponding author (berube@civil.ubc.ca)

Abstract Long-term operation of a UF membrane system for drinking water treatment under 'passive' (i.e. without backwash, chemical cleaning and permeate pumping) conditions could be sustained over extended periods. Without any sparging, a steady state permeate flux of approximately 2 $Lm^{-2}hr^{-1}$ could be maintained. Providing infrequent sparging (5 minutes/day) significantly increased the permeate flux that could be sustained (4 $Lm^{-2}hr^{-1}$). Interrupting the permeate flux (i.e. relaxation) for one hour prior to sparging further increased the sustainable permeate flux. The ability to sustain operation over an extended period of time was attributed to the microbial community that establishes itself on the membrane surface when operated under 'passive' conditions.

Keywords Low cost, membrane filtration, small/remote communities, passive operation

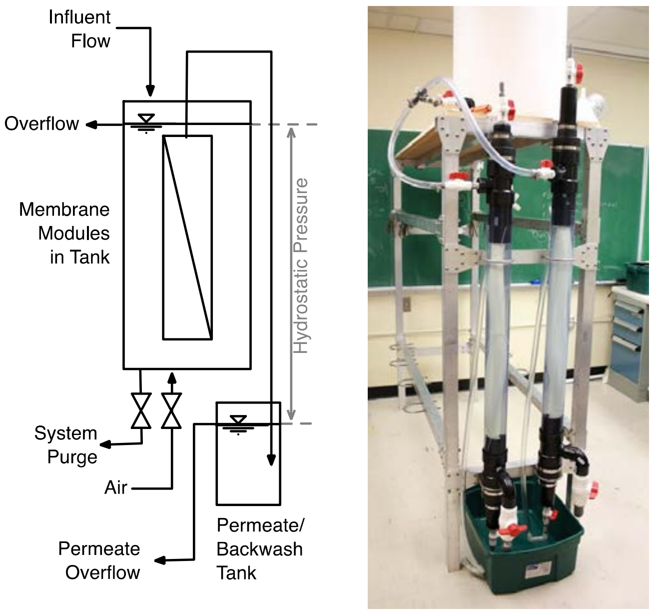
INTRODUCTION

Ultrafiltration membranes are generally considered to be too expensive and complex for drinking water treatment in small or remote communities. However, recent studies indicate that the cost and complexity of membrane systems can be drastically reduced [1,2]. Peter-Varbanets et al [1] demonstrated that stable flux conditions could be achieved without the need for any physical or chemical cleaning when operating at a low permeate flux. The ability to sustain a stable permeate flux was attributed to the microbial community that establishes itself on the membrane surface under such conditions. These communities are believed to promote the formation of a porous foulant layer on the membrane surface and degrade some of the retained material.

Oka [2] performed a systematic analysis of the contribution of different physical cleaning approaches on membrane performance. Their work confirmed that when operating at a low permeate flux (≤10 $Lm^{-2}hr^{-1}$), backwashing was not required to maintain stable operation. Although stable conditions could be sustained without gas sparging, providing periodic gas sparging significantly increased the permeate throughput. Although Oka considered periodic sparging, the frequencies investigated were relatively high. The present study considered more infrequent sparging: e.g. once per day/every other day. Infrequent sparging is of interest because if combined with daily system tank purge, the air required for sparging could be introduced by gravity (i.e. without requiring a mechanical blower). The present study also quantified the extent to which biomass accumulates on the membrane under different operating conditions.

Experimental Approach

A schematic of the bench scale membrane system used is illustrated in Figure 1a. An open top, plastic container with a working volume of approximately 80L was used as the system tank. A constant liquid level was maintained in the system tank by adding the influent at a slightly greater flow than that of the permeate and letting the excess overflow back to the feed tank. Multiple custom ZeeWeed 500 (GE Water and Process Technologies, Canada) membrane modules were present in the system tank, each with a surface area of approximately 0.002 m^2. New modules were used for each experiment. The elevation of the permeate tank was adjusted to generate the hydrostatic head necessary to produce a permeate flux of approximately 10 $Lm^{-2}hr^{-1}$ at the start of the filtration tests. A timer device (ConTolX) and solenoid valve on the permeate line were used to generate relaxation periods. Air for sparging was added (flow rate of 57 L/minute per m^2 of tank cross-sectional area) at the base of the system tank through a coarse diffuser and controlled with a timer device and solenoid valves. A valve located at the base of the system tank allows part (10%) of the reactor volume to be wasted daily. The membrane modules were conditioned by soaking them in a solution containing 750 mg/L NaOCl at pH 10 for 16 hours, permeating the solution through the membrane for 20 minutes, transferring the modules to a new solution containing 50 mg/L NaOCl at pH 10, again permeating for 20 minutes, and storing the modules in the 50 mg/L NaOCl solution until use. Prior to the start of each experiment, a bubble point membrane integrity test was performed at 69 kPa. Modules from which air was observed to escape were considered breached and were discarded. All filtration experiments were performed over a period ranging from 30 to 60 days.



a) Bench scale system b) Prototype for field validation

Figure 1. Schematic and Prototype of membrane system

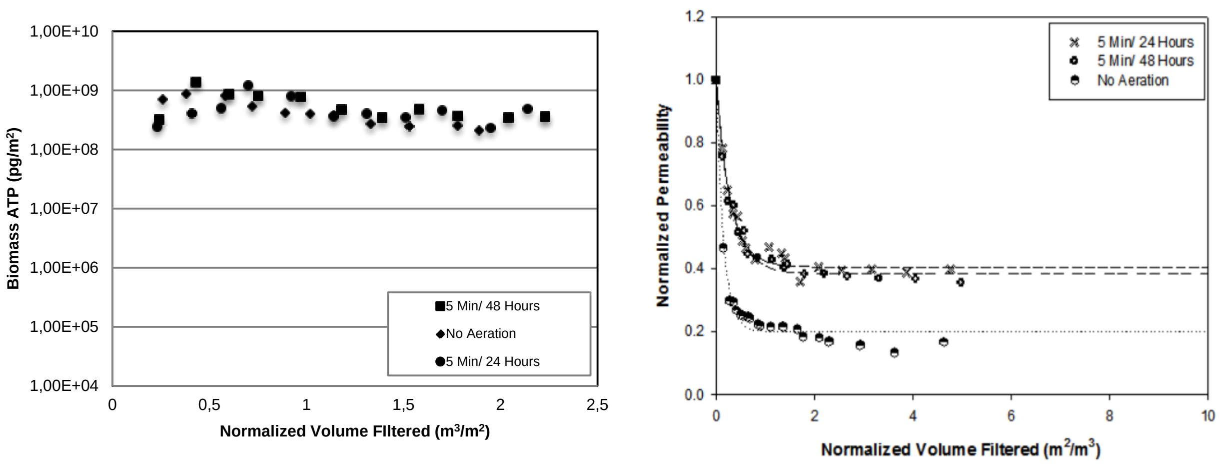
The raw water used was obtained form a local pond (Jericho Pond, Vancouver, Canada). Immediately after collection, the water was pre-filtered through a 100 µm screen and stored in the dark at 4 ^oC until used. Prior to use, the water was further filtered through a 10 µm screen and diluted with tap water to a dissolved organic concentration (DOC) concentration of approximately 5 mg/L (DOC and TOC concentration of 4.9±0.2 mg/L and 5.3 ±0.5 mg/L, respectively; UV absorbance at 256 nm and 426 nm of 10.7± 0.6 and 0.46±0.06, respectively; and turbidity of 0.22±0.03 NTU; ± based on a 90% confidence interval). All experiments were performed at a temperature of 22 °C.

The organic composition of the raw water and the permeate samples was characterized using total organic carbon analysis (Phoenix 8000 TOC analyser, Dohrmann, US) as well as specific light absorption at 254 nm (UV300 UV-vis spectrometer, Spectronic Unicam, US). Prior to all analyses, samples were pre-filtered using 0.45 µm cellulose nitrate membrane filters (Cat. # 09-719-555, Fisher Scientific, CA). Any samples that could not be analyzed immediately were stored at 4 °C. Adenosine Triphosphate (ATP) was determined in the raw water and the material on the membrane as an indicator for biological activity using LuminUltra Biofilm test kit (LuminUltra, CA). Membrane modules were periodically harvested from the system tank for ATP analysis. After harvesting, individual membrane fibres cut from the modules were placed into extraction tubes and mechanically vortexed for 3 minutes to separate the biomass from the membrane and immediately analyzed for ATP.

RESULTS AND DISCUSSION

As previously reported by others [1], the amount of biomass present on the membrane (measured as mass of ATP extracted from the membrane surface) was significantly greater than expected based on a mass balance analysis of the ATP in the system, indicating substantial microbial growth on the membrane surface.

Providing infrequent sparging (5 minute period per day or every other day) did not result in a significant reduction in the amount of biomass present on the membrane surface compared to conditions with no sparging (Figure 1a). However infrequent sparging significantly increased the steady state permeability compared to conditions with no sparging (Figure 2b). With infrequent sparging, a permeate flux of approximately 4 $Lm^{-2}hr^{-1}$ could be sustained, while without any sparging, the sustained permeate flux was 2 $Lm^{-2}hr^{-1}$.



a b

Figure 2. Typical impact of air sparging. (a: ATP; b: Normalized permeability, with lines corresponding to an exponential relationship fitted to the experimental data)

The normalized permeability of 0.2 with no air sparging is similar to that reported in a previous study for conditions with no air sparging [2]. However, the normalized permeability that could be sustained in the present study with infrequent sparging (5 minutes every 24 or 48 hours) was substantially greater than that previously reported when considering intermittent sparging (5 minutes every 25 minutes, 5 minutes every 4 hours or 30 minutes every 4 hours) [2]. The greater sustained permeability with infrequent air sparging observed in the present study compared to that previously reported with intermittent air sparging was attributed to the difference in the start-up conditions. In the present study, no acclimatization period was applied prior to the start of the filtration tests, as opposed to the extensive acclimatization period applied in the previous study with intermittent aeration [2].

When harvesting membrane fibers for microbial analyses, the foulant layer was observed to readily slough off the membrane surface over time (Figure 3a), suggesting that a permeate flux interruption period (i.e. relaxation step) prior to infrequent sparging could further increase the steady state permeability. Although interrupting the permeate flux for one hour prior to sparging did not impact the amount of biomass on the membrane, it further increased the permeability (Figure 3b). Extending the relaxation period beyond 1 hour negatively impacted the steady state permeability and reduced the amount of biomass on the membrane. It is likely that the negative impact is related to a reduction in nutrient load to the microorganisms when permeation is interrupted for an extended period of time; however further research is required to confirm this hypothesis.

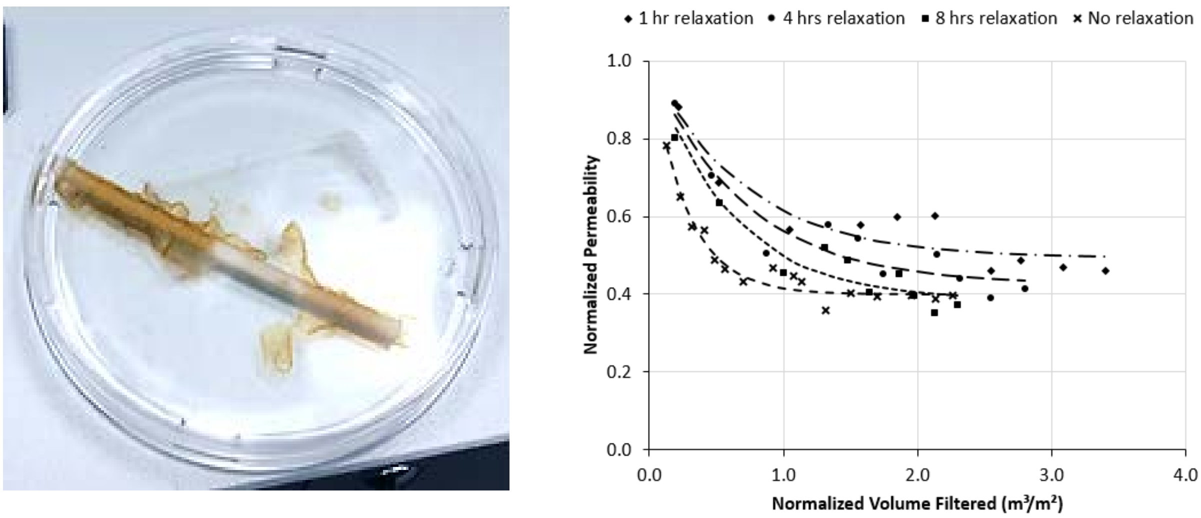


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Figure 3. a) typical image of biomass sloughing off membrane and b) impact of relaxation on the normalized permeability (with lines corresponding to an exponential relationship fitted to the experimental data)

Approximately 50 % of the TOC in the raw water could be removed during treatment. The removal was attributed to a combination of physical straining and biological hydrolysis and degradation of organic material present in the raw water.

Results from the present study are currently being field validated in a prototype system (Figure 1c) that operates using gravity head for permeation, sparging and purging.

CONCLUSIONS

Sustained conditions could be achieved without backwashing, air sparging or chemical cleaning, indicating that these fouling control measures can be eliminated, simplifying the mechanical and operational complexity of submerged hollow fiber ultrafiltration systems. The ability to achieve sustained conditions was attributed to the microbial community that establishes itself on the membrane surface.

Without fouling control measures, the permeability that could be sustained was low: approximately 20% of that which can be maintained with conventional membrane filtration systems. As a result, the permeate flow that could be sustained was only approximately 2 $Lm^{-2}hr^{-1}$. By retaining a small amount of infrequent air sparging (i.e. a few minutes daily), the permeability could be significantly increased, resulting in a sustained permeate flow of approximately 4 $Lm^{-2}hr^{-1}$. Incorporating a daily 1-hour relaxation period (prior to sparging) further increased the sustainable permeability, yielding a sustained permeate flow of approximately 5 to 6 $Lm^{-2}hr^{-1}$. These two fouling control measures (i.e. infrequent air sparging and relaxation periods) are of particular interest because they can be implemented with minimal mechanical and operational complexity.

REFERENCES

[1] Peter-Varbanets M., Margot J., Traber J., Pronk W. (2011) Mechanisms of membrane fouling during ultra-low pressure ultrafiltration, Journal of Membrane Science, 377:42-53.

[2] Oka P., Khadem, N., Bérubé, P.R., Operation of Passive Membrane Systems for Drinking Water Treatment, submitted for publication in Water Research, 2016.

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