Desalination and Water Treatment 9 (2009) 82–85
www.deswater.com

Observation of cake layer formation and removal on microporous hollow-fibre membranes

S. Buetehorn[a,*], M. Brannock[b], P. Le-Clech[b], G. Leslie[b], D. Volmering[c], K. Vossenkaul[c], T. Wintgens[a], T. Melin[a]

[a]*Chemical Process Engineering, AVT, RWTH Aachen University, Aachen, Germany*
email: steffen.buetehorn@avt.rwth-aachen.de
[b]*UNESCO Centre for Membrane Science and Technology, University of New South Wales, Sydney, Australia*
[c]*Koch Membrane Systems GmbH, Aachen, Germany*

Received 15 September 2008; Accepted 20 March 2009

1. Introduction

In submerged membrane bioreactor (SMBR) processes, air is injected into the stationary suspension to induce flow and to generate shear at the surface of the membrane [1]. Besides this, the bubble-induced movement of hollow-fibres is contributing to the removal of the cake layer [2]. This air bubbling sequence is investigated at different scales (single fibres, small fibre bundles) and under different operating conditions (permeate fluxes, aeration rates, solids concentrations) within the framework of this study. The overall objective is to evaluate the impact of operating parameters, characteristics of the model suspension and membrane module design parameters on the efficiency of air bubbling.

Within previous experiments [3], cross-flow filtration tests at constant transmembrane pressure (TMP) have shown that the long-term permeate flux is increasing with an increasing cross-flow velocity, a decreasing solids concentration, a decreasing average particle size (for small particle size to pore size ratios) and a decreasing dynamic viscosity, whereas the long-term permeate flux is independent of feed pressure variations. These trends are consistent with published theories which demonstrate that the thickness of the reversible cake layer increases with a decreasing cross-flow velocity and an increasing feed pressure [4]. While an increase in cross-flow velocity is leading to an enhanced entrainment of deposited matter and thereby to a higher permeate flux, a higher feed pressure is leading to a temporary increase in permeate flux only. However, this benefit is compensated by an increased filtration resistance due to a thicker cake layer, so that the long-term permeate flux is, within a certain range, independent of the driving force of the process [5].

This paper reports about lab-scale experiments conducted in submerged mode with different degrees of simplification. In comparison to the well-defined hydrodynamic conditions within the above-mentioned cross-flow test cell equipped with a single, not moving fibre, the complexity of the system is increased stepwise by applying air bubbling to induce a tangential flow and by taking fibre movement and fibre-fibre interactions into account.

2. Materials

For all filtration tests, single hollow-fibre membranes and small hollow-fibre bundles of the PURON® system provided by Koch Membrane Systems GmbH (KMS) were used. According to the manufacturer, these microfiltration membranes consist of polyether sulphone (PES) as a source material and show an outer diameter of 2.6 mm, an inner diameter of 1.2 mm and a nominal pore diameter of 0.04 µm. An average pure water permeability of a virgin hollow-fibre membrane of approximately 1400 L/(m^2 h bar) was determined [6].

As a model substance, an alkaline, aqueous dispersion of colloidal silica particles (B9950) with a size distribution in-between 20 and 150 nm was used. The stock suspension was kindly provided by eka AKZO NOBEL and consists of amorphous spherical SiO_2 particles with a slightly negative surface charge at pH = 9. The desired solids concentration was adjusted by adding pure water to the stock suspension (stock solids concentration = 31.8 vol. %). According

*Corresponding author.

Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.

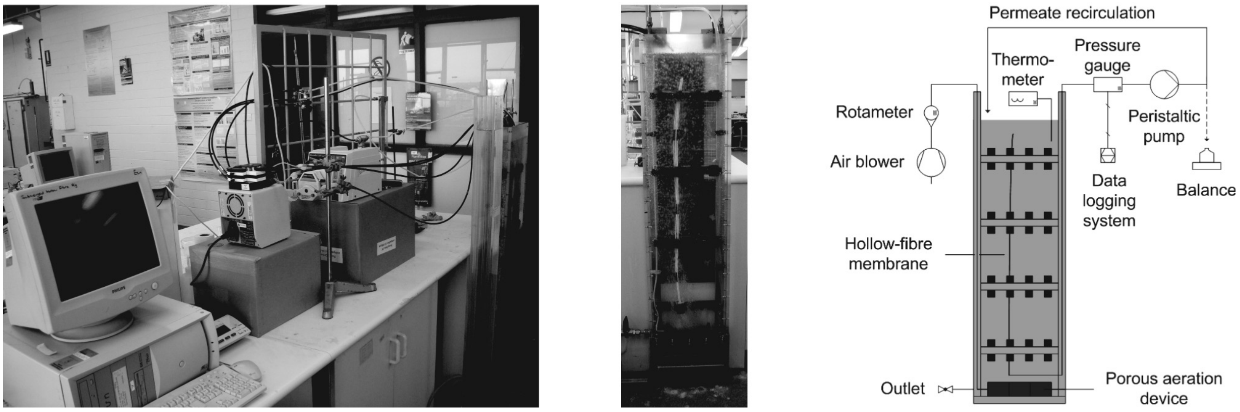

Fig. 1. Experimental setup for submerged filtration and direct observation.

to own rheological measurements [3], the model suspension consisting of silica particles in water shows Newtonian characteristics and water viscosity in a range of particle concentration of up to 3.2 vol. %. Moreover, it was found that xanthan solutions as a dispersant are capable of representing shear-thinning characteristics of activated sludge according to the Rosenberger model [7] properly. However, model suspensions of silica particles in xanthan solutions were not used for these filtration tests since the xanthan molecules cause membrane fouling and permeate through the membrane leading to an unrealistic permeate viscosity.

3. Methodology

An existing experimental setup was modified, see Fig. 1, and the respective test protocols were adapted from [2]. The filtration tests were conducted at constant permeate flux and constant aeration rate while the transmembrane pressure (TMP) was monitored versus time. The membrane bundle prototypes were fixed at the bottom end only, so that the fibres were free to move laterally at the top end, which is characteristic for this module configuration. In complementary test series, fixing elements were connected to the loose ends of the membranes to avoid fibre movement. Each submerged filtration experiment was lasting for approximately 2.5 h. No permeate backwashing sequences have been conducted.

Besides the silica filtration tests, a video camera was used to monitor the bubble-induced fibre movement. Since the model suspension containing silica has a milky appearance, pure water without silica particles was filtrated during the second period of investigations in order to facilitate a direct observation of fibre motion. However, the overall hydrodynamic conditions inside the tank are assumed to be independent of the solids content since the impact of particle concentration on the dynamic viscosity of the suspension was found to be negligible [3].

4. Results and discussion

Initial results of silica filtration at a solids concentration of 0.4 vol. %, a setpoint permeate flow rate of 2.0 mL/min and a fibre length of 0.75 m are presented in Figs. 2 to 4. In these diagrams, both the TMP and the permeate flux are plotted versus time for 4 respectively 2 different test runs under the same operating conditions. During the first 2.5 h of filtration, the permeate flux (determined manually by weighing the amount of permeate over time) was in the range of 21 to 23.5 L/(m^2 h) and was slightly decreasing due to an increasing thickness of the cake layer and by that increasing backpressure within the permeate extraction line. However, it was assumed that the decrease in permeate flux is negligible, i.e. the experiments were conducted under constant permeate flux operation.

The curves are indicating that the evolution of TMP is sufficiently reproducible for this early stage of experiments. While the initial TMP is nearly the same, a deviation of final TMP at the end of each test run is observable, particularly with respect to test run 001 in Fig. 3 compared

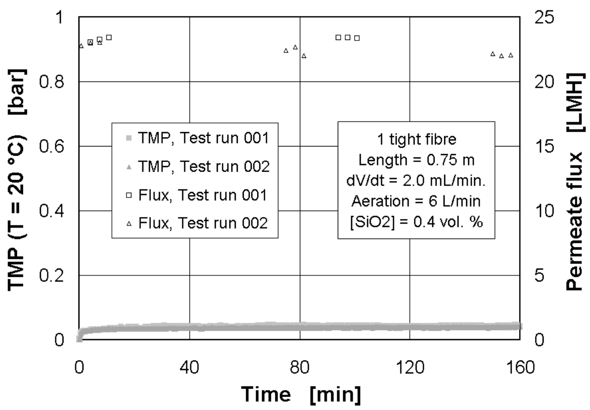

Fig. 2. Transmembrane pressure (TMP) and permeate flux vs. time for a bundle with a single, tight fibre (fibre fixed at both ends) at 6 L/min aeration rate.

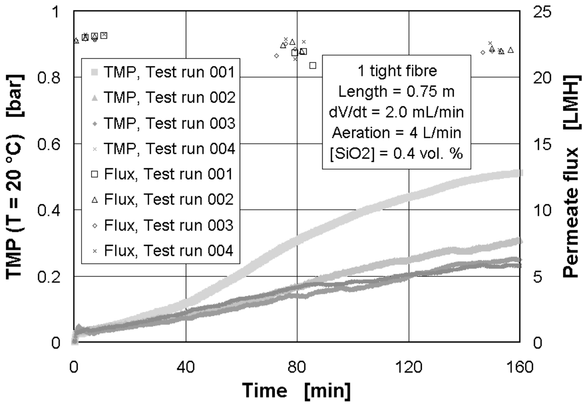

Fig. 3. Transmembrane pressure (TMP) and permeate flux vs. time for a bundle with a single, tight fibre (fibre fixed at both ends) at 4 L/min aeration rate.

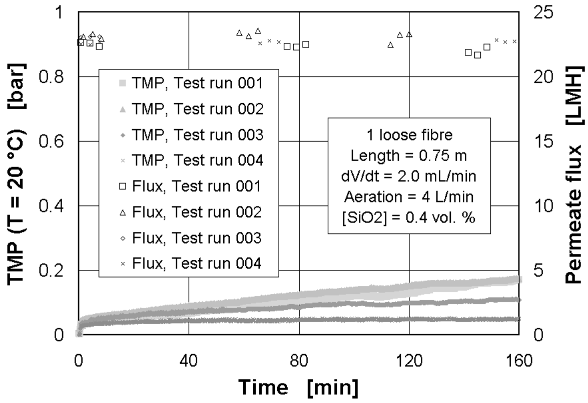

Fig. 4. Transmembrane pressure (TMP) and permeate flux vs. time for a bundle with a single, loose fibre (fibre fixed at the bottom end only) at 4 L/min aeration rate.

to all others. These inaccuracies might be due to differences in pure water permeability of the virgin membrane samples and/or the transient character of the multiphase flow pattern and the bubble-induced fibre movement, which are affecting the reproducibility of experiments.

With an increasing aeration rate, the bubble-induced tangential flow of the model suspension is increasing, which is in turn leading to an enhanced removal of deposited matter from the surface of the membrane. The resulting decrease in filtration resistance is observable by means of a decreasing TMP as presented in Fig. 2 compared to Fig. 3 for bundles with not moving fibres (i.e. tight fibres fixed at both ends). Furthermore, the standard deviation of TMP at the end of each test run as well as the increase of TMP during the experiment is much lower for an aeration rate of 6 compared to 4 L/min. This might be due to a complete removal of deposited matter under non-critical aeration conditions, i.e. nearly no cake layer was formed on the membrane for an aeration rate of 6 L/min.

Despite the TMP variations under the same operating conditions, a significant decrease in final TMP was observable when the fibres were free to move laterally at the top end of the bundle, see Fig. 4 compared to Fig. 3. This trend is presumably due to the impact of (i) additional shear forces originating from the lateral fibre movement within the suspension and (ii) collisions of the moving fibres with the support frame within the tank (see also Fig. 1).

5. Conclusions and outlook

Hydrodynamics in submerged membrane bioreactors (SMBRs) have been investigated with different degrees of simplification. Since the shear forces at the surface of the membrane are easier to predict in cross-flow than in submerged filtration processes [8], a cross-flow setup was used during the first stage of this project. The respective results, which have been presented within a previous publication [3], have shown that the cake layer formation and removal is following the reversible cake layer formation theory [4].

Moving forward, a submerged filtration setup has been put into operation and initial results of the start-up period are presented within this paper. In agreement with the cross-flow investigations, an increase in aeration rate, followed by an increase in bubble-induced liquid cross-flow, is leading to an enhanced removal of the cake layer and by that an improved filtration performance of a system with not moving fibres. Moreover, it was observable that the TMP is nearly constant in case of an aeration rate of 6 L/min, presumably due to non-critical aeration conditions.

Subsequently, fibre movement was taken into account. It was found that the final TMP is much lower if the fibres are free to move laterally at the top end of the bundle. These optimised filtration conditions are possibly caused by increased shear forces at the membrane surface due to fibre motion and/or the interaction of the fibre and the support frame within the tank, which is consistent with already published results [2].

During the last part of the project, a video camera was used to determine the intensity of fibre movement for single hollow-fibres and bundles consisting of more than one fibre. The overall objective of this approach is to estimate the impact of aeration conditions and bundle design parameters on the intensity of fibre movement in terms of amplitude, frequency and velocity. By that, the influence of fibre movement and fibre-fibre interactions on the filtration performance of the system will be investigated within future studies. For this purpose, a quantitative analysis of the raw data in terms of a frame-by-frame image processing is currently conducted in MATLAB®.

However, although a quantitative image processing is still to be done, an increasing intensity of fibre motion was observable with an increasing aeration rate and a decreasing packing density. These trends are most likely caused by more pronounced interactions of the flow pattern and the fibres at higher aeration rates respectively less pronounced fibre-fibre interactions at lower packing densities.

Acknowledgements

Financial support of the European Commission is acknowledged. This research work was funded within the EUROMBRA project (contract no. 018480) and co-financed by the AMEDEUS project (contract no. 018328) under the Sixth Framework Programme (Priority "Global Change and Ecosystems"). EUROMBRA and AMEDEUS are part of the MBR-NETWORK Cluster. The authors would like to thank eka AKZO NOBEL, Daniela Tacke and Prof. Dr. Johannes Pinnekamp from the Institute for Environmental Engineering (ISA) at RWTH Aachen University for their cooperation and the German Academic Exchange Service (DAAD) for the financial support.

References

[1] Z.F. Cui, S. Chang, A.G. Fane. J. Membr. Sci. 221 (2003) 1–35.
[2] F. Wicaksana, A.G. Fane, V. Chen. J. Membr. Sci. 271 (2006) 186–195.
[3] S. Buetehorn, F. Carstensen, T. Wintgens, T. Melin, D. Volmering, K. Vossenkaul. Desalination (submitted).
[4] T. Melin and R. Rautenbach, (Eds.), Membranverfahren–Grundlagen der Modul–und Anlagenauslegung, Springer, Berlin, 2007.
[5] L. Wang, L. Song. J. Membr. Sci. 160 (1999) 41–50.
[6] S. Buetehorn, C.N. Koh, T. Wintgens, D. Volmering, K. Vossenkaul, T. Melin. Desalination 231 (2008) 191–199.
[7] S. Rosenberger, K. Kubin, M. Kraume. Eng. Life Sci. 2 (2002) 9.
[8] P. Le-Clech, V. Chen, T.A.G. Fane. J. Membr. Sci. 284 (2006) 17–53.