Immersed flat-sheet membrane bioreactors for lignocellulosic bioethanol production

Amir Mahboubi Soufiani

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University of Borås, Allégatan 1, Borås, Sweden.

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Faculty Opponent is:

Prof. Huu Hao Ngo

School of Civil and Environmental Engineering,

University of Technology Sydney, Australia

PhD thesis is available at
Swedish Centre for Resource Recovery
University of Borås
SE-501 90 Borås, Sweden. +46(0) 33 435 4000

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Abstract

The rising awareness of the environmental, economic and socio-political impacts of over-exploitation of fossil-based fuel and energy sources, have motivated the transition toward more sustainable and renewable energy sources. Lignocellulosic materials (e.g. agricultural residues) are potential candidates for sustainable bioethanol production that contributes to the replacement of fossil fuels. However, to have an economically feasible and commercialized process, issues associated with lignocellulosic bioethanol production in upstream, fermentation and downstream processing stages should be alleviated. Membrane bioreactors with their great capabilities in semi-selective separation are promising options for making a breakthrough in lignocellulosic biorefinery processes. Therefore, in this thesis, different membrane modules and immersed membrane bioreactors (iMBRs) set-ups were developed and applied to take advantage of this long-matured water and wastewater treatment technique in remediation of challenges in the lignocellulosic bioethanol production.

Thus, In order to intensify and optimize the lignocellulosic bioethanol production process, pressure-driven flat sheet microfiltration iMBRs were integrated into different processing stages. The application of a continuous iMBR led to a high ethanol productivity and yield (83% of theoretical yield) at high suspended solid content (up to 20% w/v) of wheat straw hydrolysate, and successful bacterial contamination separation from yeast (up to 93% removal). Moreover, using double-staged iMBRs for continuous hydrolysis-filtration and co-fermentation-filtration led to an effective separation of lignin-rich solids (up to 70% lignin) and sugar streams from the hydrolysate, and yeast cells from the fermentation product stream, stable long-term filtration performance (up to 264 h) at filtration flux of 21.9 $l.m^{-2}.h^{-1}$. In this thesis, filtration performance was thoroughly investigated, and effective physical fouling preventive approaches were applied to guarantee continuous bioprocessing. In addition, in order to remediate issues related to high content of inhibitors and presence of sequentially-fermented hexose and pentose saccharides in lignocellulosic fermentation, the cell-confinement approach of reverse membrane bioreactor (rMBR), which merges the benefits of iMBRs and cell encapsulation techniques, was introduced and applied in this thesis. It was observed that the high local cell density and diffusion-based mass transfer in the rMBR promoted co-utilization of sugars, and boosted cell furfural detoxification at concentrations of up to 16 $g.l^{-1}$. Moreover, considering the needs of rMBR processes for cell recirculation, membrane envelope degassing, and media conditioning, a novel membrane module was designed, developed, and patented in this thesis work.

Keywords: Lignocellulosic bioethanol, immersed membrane bioreactor, membrane fouling, reverse membrane bioreactor