Monitoring the algae biomass growth developed on hollow fiber membrane bioreactor

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Abstract: This work focuses on using non-destructive imaging techniques to monitor in-situ the formation of algae biomass on hollow fiber membrane bioreactor treating wastewater. Optical Coherence Tomography (OCT) was employed to acquire cross-sectional scans of the algae growth in real-time under continuous operation. The proposed approach allowed evaluating in real-time the impact of the biomass on the bioreactor performance in terms of TMP increase and permeate quality.

Keywords: Algae harvesting, Fouling, MBR, Wastewater treatment, flux.

1. Introduction

Diverse groups of microalgae have attracted attention as unconventional sources of biofuels, food, and valuable products owing to their capability to turn CO_2 and nutrients into valuable biomass and oxygen via photosynthesis. Nonetheless, using the potential benefits of algal biotechnologies to offset their high production cost remains a major challenge. Most of the costs are related to harvesting and dewatering (Huang et al., 2012).

In diluted growth, the small sizes of microalgae cells demand large inputs of energy and equipment for harvesting and dewatering. Thus, membrane separation technologies have been proposed as an efficient alternative to remove a wide range of algal cells, whilst increasing the water feed inputs and biomass production. The major bottleneck of membrane filtration results from the accumulation of algal cells and their organic matter on the membrane surface and within the membrane pores, in the so-called phenomenon of biofouling (Novoa et al., 2021).

Considering the negative impact of biofouling on the water flux and energy consumption, its control is essential to ensure the operation of algal harvesting systems (L Fortunato et al., 2020b). However, the success of these mechanisms relies on site-specific environmental and operating conditions. Thus, inadequate fouling control strategies might significantly increase the consumption of energy and thereby hamper the overall system performance(L Fortunato et al., 2020c). In this study, the algal biomass growth on hollow fiber membrane bioreactor was performed in real-time with Optical Coherence Tomography (OCT), providing new insight into the impact of the algae on the process performance.

2. Material and Methods

A seed of the microalgae *Chlorella vulgaris* (UTEX 259) was pre-cultivated autotrophically in Modified Bold's Basal Medium (BBM) (Sigma-Aldrich ®). Upon 120 days of acclimatization, the biomass concentration was adjusted to 500 mg/L at a hydraulic residence time (HRT) of 12 h. The reactor, with a working volume of 2 liters, was continuously illuminated using white LED lights (and continuously operated dosing secondary synthetic wastewater with no organic carbon source and total nitrogen and dissolved inorganic phosphorous concentrations of 60 and 10 mg/L, respectively (Novoa et al., 2020).

Compressed air was the sole source of inorganic carbon, it was filtered and then bubbled through air diffusers into the reactor at a rate of 30 L/h. The temperature was kept at 25°C, and the pH was kept between 7 and 8. The *Chlorella vulgaris* cell suspension was continuously fed into an automatic filtration unit (Osmo InspectorTM Convergence, The Netherlands). A hollow fiber PVDF membrane module (GETM, USA), with a pore-size of 16 nm, was used as solid-liquid separator at a flux of 20 LMH. The cell suspension was circulated through the membrane filtration unit at a speed of 2 L/h, where permeate was extracted whilst retentate was recirculated back into the reactor. The permeate samples were collected from the Osmo Inspector TM filtration over time. The concentration of ATP was measured using the ATP Analyzer (Celsis, USA). The fouling propensity of the APMBR was assessed by measuring the increase in transmembrane pressure (TMP). Further, an optical coherence tomography unit (OCT, Thorlabs GANYMEDE spectral-domain OCT system with a central wavelength of 930, Thorlabs, GmbH, Dachau, Germany) equipped with a 5X telecentric scan lens (Thorlabs LSM 03BB) was used to monitor the formation and growth of the algal biomass on a submerged hollow fiber membrane filtration unit. The 2D cross-sectional scans were acquired both perpendicular and parallel to the fiber direction (Fig. 1). To analyze and evaluate the algae biomass morphology, the OCT scans were preprocessed using FiJi software, whereby it was possible to calculate the thickness of the algal layer developed onto the membrane surface. The latter was calculated using a customized MATLAB code (Fortunato et al., 2019).

3. Results and discussion

In this study, the algae biomass growth was monitored under continuous operation with OCT. The OCT uses back-scattered light enabling acquiring 2D or 3D scans without the use of any contrast agents. The approach has recently gained momentum on the study of fouling in membrane filtration systems (L Fortunato et al., 2020a; Pathak et al., 2018).

The OCT enabled performing a time-series development of the biomass over time on the hollow-fiber *in-situ* without interrupting the operation. Afterward by performing image analysis on the OCT scans it was possible to quantify the biomass growth over time.

However, it is worth noting that acquiring OCT cross-sectional scans on hollow fiber membrane presents more challenges with respect to flat membrane (Fig. 1 and 2). To this extent, tubules membrane geometries complicate the non-destructive monitoring in the steps of image acquisition (i) and image processing (ii). In fact, the number of OCT studies reported in the literature on non-flat membrane configuration is limited (L Fortunato et al., 2020a). The first aspect that needs to be taken into account is the difference in hydrodynamics and packaging density between the two configurations (hollow fibers and flat membranes). The presence of multiple fibers in a single module complicates the selection of a clear portion of the membrane. Moreover, the fibers tend to move within the reactor over time, with the risk of losing the selected monitoring area.

Another point that needs to be considered when using a tubular membrane geometry is the possibility of performing the imaging on two different modalities: parallel (i) or perpendicular (ii) to the membrane fiber. As shown in Fig.1 and Fig. 2, the first option allows imaging the cross-section of circular membrane. The first limitation observed in the perpendicular case is that most of the scan is out-of-focus. In fact, the OCT imaging is affected by short ranging distance and narrow imaging field of view (Song et al., 2016), whereas only a small part of the acquired scan can be in focus. Moreover, the cross-section round membrane geometry also represents an obstacle for the image processing and characterization of the morphological proprieties of the biomass deposited on the membrane (Fig. 2). In particular, the bottleneck is represented by the image segmentation, in which specific algorithms are applied to distinguish the different segments of the OCT scan (i.e. biomass vs membrane). On the other side, monitoring a part of the membrane parallel to the fiber has less complication due to the flatness of the membrane surface, enabling using approaches and imaging tools already developed for the flat membrane modules.

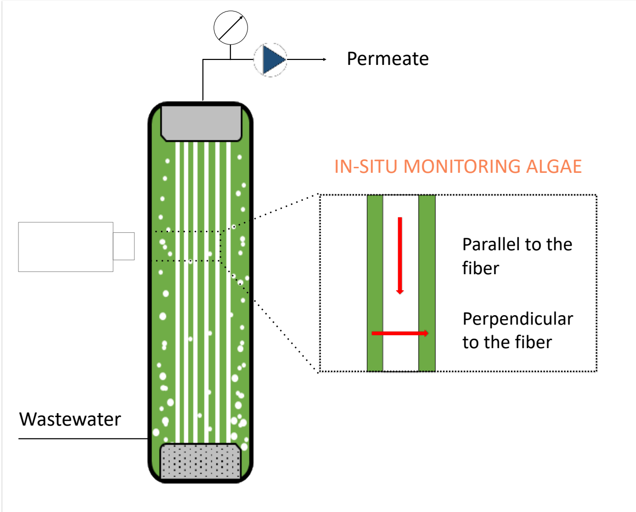

Figure 1. Schematic drawing of the experimental setup. In-situ monitoring was performed under continuous operation with Optical Coherence Tomography (OCT), allowing to monitor the algae growth in two positions with respect to the hollow fiber membrane direction, parallel (i) and perpendicular to the fiber (ii).

In this study, it was possible to quantify the algae biomass deposition over time by performing in-situ monitoring on a portion of the membrane parallel to the fiber. The algal biomass reached an average thickness of 93 um after 180 minutes of filtration (Fig. 3A). The increase in biomass deposition was followed by the rise of fouling in the bioreactor. In fact, once the biomass was formed on the membrane, it provided additional resistance to filtration, resulting in an increase of TMP.

As highlighted by Fig. 3A, a linear correlation was observed between the algae biomass thickness and the TMP increase. While the biomass had a negative impact on the membrane performances, it is worth noting that it had the opposite effect on the permeate quality. As shown in Fig. 3B, the ATP concentration in the permeate decreased over time due to the positive effect of the additional filtration layer provided by the algae deposited on the membrane surface. Indeed, as previously reported in the literature, the fouling layer can improve the removal of some specific compounds (BouNehme Sawaya and Harb, 2021; Wang et al., 2017).

4. Conclusion

In this study, the biomass growth on a hollow fibers membrane bioreactor was monitored under continuous operation with Optical Coherence Tomography. Monitoring the biomass on a hollow fiber membrane presents more complications with respect to the flat membrane.

The *in-situ* monitoring allowed to link the growth of algae biomass with the bioreactor performance. This provided insight into the operation of algae bioreactors both for biomass harvesting operation or for water treatment purposes. It was possible to assess the trade-off between the energy consumption in the system and algae growth on the membrane. Moreover, this approach could be usefully employed to evaluate the impact of cleaning strategies aiming to restore the membrane performance or recover biomass on the membrane.

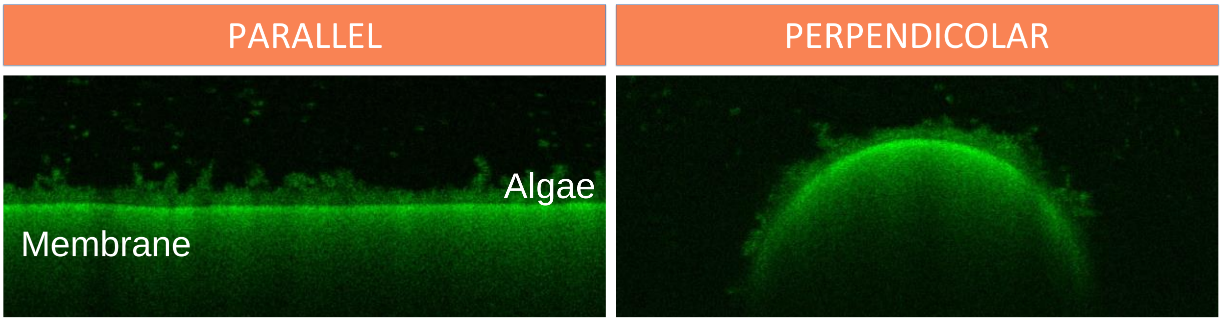

Figure 2. OCT scans acquired under continuous operation in the algae membrane bioreactor. The algae growth was monitored in two positions with respect to the hollow fiber direction, parallel (left) and perpendicular to the fiber (right).

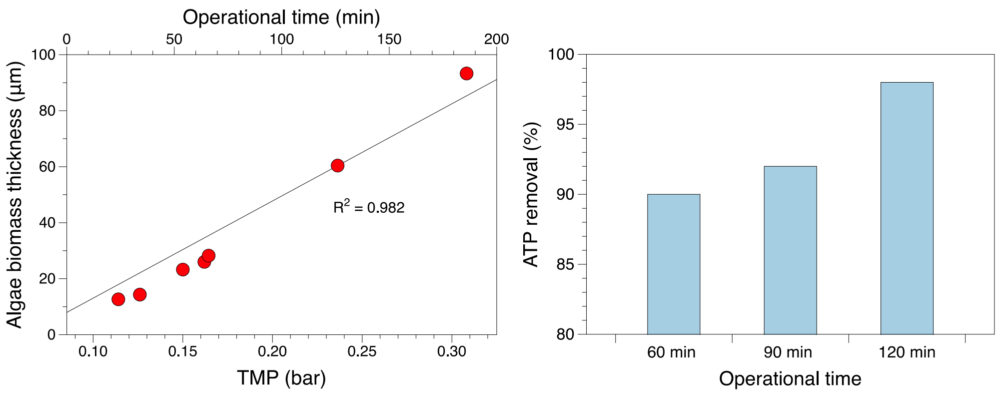

Figure 3. (A) Correlation between algae biomass thickness deposited on the hollow fiber membrane and TMP increase in the algae membrane bioreactor. (B) ATP removal in the permeate. Over time, the increase of biomass algae on the membrane led to an increase of the fouling and a reduction of the ATP on the permeate.

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