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Characterization of membrane fouling in submerged ceramic membrane photobioreactors fed with effluent from membrane bioreactors

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HIGHLIGHTS

- Three SCMPBRs were operated at 72-, 24- and 6.5-h HRT.
- Membrane fouling rate increased with lower operating HRTs through increased of SMPc.
- At long HRT (72 h), hydrolysis was induced in cake layer formed on membrane surface.
- At short HRT (6.5 h), fouling occur via cake layer compaction at high convection rate.
- Macromolecular compound contributed more to membrane fouling than soluble compound.

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ABSTRACT

The effect of hydraulic retention time (HRT) on the membrane fouling behavior of submerged ceramic membrane photobioreactors (SCMPBRs) fed with effluent from a submerged ceramic membrane bioreactor (SCMBR) was investigated. The effluent from a SCMBR was continuously fed to three SCMPBRs operated at different HRTs (72, 24, and 6.5 h) for a period of 100 d. Results of the effect of mixed liquors characteristics on fouling showed that mixed liquor suspended solids (MLSS), zeta potential and extracellular polysaccharides (EPS) were not the key factors leading to various fouling behaviors for the SCMPBRs. Membrane fouling rates increased with lower operating HRTs through increased production of carbohydrates in soluble microbial product (SMP). The transmembrane pressure (TMP) value of $SCMPBR_{6.5h}$ exceeded 30 kPa after 68 d of operation, while the TMP of $SCMPBR_{72h}$ and $SCMPBR_{24h}$ were relatively constant throughout the 100 d. Different membrane fouling phenomena were observed at different HRTs. It was noted that biological reactions (e.g., hydrolysis) were induced on the biofilm/biocake layer formed on the membrane surface when operating SCMPBR at long HRT (i.e., 72 h). For SCMPBR operating at short HRT (i.e., 6.5 h), fouling layer and active layer developed on the membrane surface facilitated sieving of colloidal particles and organics. The detailed composition of the organic compounds on membrane foulants in the $SCMPBR_{6.5h}$ showed that carbohydrates and proteins were the major foulants. The finding of much higher organic in non-filtered membrane foulant samples as compared to filtered samples together with the findings from membrane fouling resistance distribution, molecular weight distribution (MWD) and particle size distribution (PSD) indicated that macromolecular compounds contributed more to membrane fouling than those small molecular compounds or soluble compounds.

1. Introduction

A membrane photobioreactor (MPBR) is defined as a process associating the culture of photosynthetic microorganisms with a continuous separation by membrane filtration of the biomass and the water treated [1]. Microalgae have been cultivated in either open ponds or photobioreactors using wastewater for both nutrient removal and microalgal cultivation. Photobioreactors are gaining popularity as they are able to provide a controlled environment that can be tailored to the specific demand of highly productive microalgae to attain a consistently good annual yield of oil [2]. Some researchers cultivated microalgae in photobioreactors to remove nutrients from wastewater or treated wastewater and

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Nomenclature

DOM	dissolved organic matter
DON	dissolved organic nitrogen
EEM	excitation-emission matrix
EPS	extracellular polysaccharides
HPLC	high performance liquid chromatography
HPSEC	high performance size exclusion liquid chromatography
HRT	hydraulic retention time
LC-OCD	liquid chromatography-organic carbon detection
LMH	litre per meter square per hour
LMWs	low molecular weight substances
MBR	membrane bioreactor
MF	microfiltration
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
MPBR	membrane photobioreactor
MW	molecular weight
MWD	molecular weight distribution
OC	organic carbon
PSD	particle size distribution
SCMBR	submerged ceramic membrane bioreactor
SCMPBR	submerged ceramic membrane photobioreactors
SEM	scanning electron microscope
SMP	soluble microbial product
SRT	solids retention time
TMP	transmembrane pressure
TOC	total organic carbon
UF	ultrafiltration

subsequently, harvested microalgae biomass for biofuel production [3,4]. However, the harvesting of biomass was based purely on sedimentation, hence washout might occur if the biomass could not settle well. Due to the harvesting issue, combined wastewater treatment by microalgae and subsequent biodiesel production were done mostly on a batch or semi-continuous mode. From a practical standpoint, a system that is able to continuously separate microalgae biomass from the treated effluent will be preferable for real-world applications.

To overcome this problem, membrane filtration was utilized to continuously separate the microalgae biomass from the treated effluent [5]. Microfiltration (MF) and ultrafiltration (UF) membranes offer the advantage of complete retention of microalgae biomass, allowing higher concentration of microalgae biomass to be retained in the MPBR. The influent can be fed and the treated effluent can be produced in a continuous manner. However, the widespread application of membrane filtration for microalgae separation is hindered by high maintenance and operation costs, resulted largely from membrane fouling. In an MPBR, membrane fouling is a process of accumulation of organics or inorganic onto the membrane surface or into the membrane pores brought about by the interaction between the membrane and microalgae suspensions.

Thus far, all reported studies have assessed membrane fouling by microalgae using commercial culture medium either in a batch or semi-continuous operation mode. Conclusions drawn from those studies on concentration of microalgae biomass using commercial culture medium would be different for studies on nutrient removal from treated wastewater and biomass harvesting. Membrane fouling in continuously operated SCMPBRs fed with SCMBR effluent was characterized in order to implement better strategies to prevent or alleviate this problem. In this study, membrane fouling mechanisms and contributing factors were investigated in a systematic approach for the SCMPBR used for combined continuous harvesting process with photobioreactor for growing microalgae using SCMBR effluent.

In our previous study, the effectiveness of *Chlorella vulgaris* to remove nutrients from SCMBR effluent and their ability to accumulate biomass for biodiesel production has been shown [6,7]. This study adds on to current knowledge by focusing on membrane fouling characteristics at different HRTs so that there will be a better understanding of the various factors involved in microalgal biomass cultivation and accumulation at various operational modes. The effect of HRT was observed by varying the HRT of the three SCMPBRs by keeping other operating parameters constant to elucidate factors causing membrane fouling.

2. Materials and methods

2.1. Algal strain and subculture

C. vulgaris CCAP 211/11B was obtained from the Culture Collection of Algae and Protozoa, Argyll, UK and was cultured under continuous illumination (7500 lux) at 25 °C. More detailed information about the inoculation of sub-cultured cells into SCMPBRs is available in Low et al. [7].

2.2. Aerobic SCMBR and SCMPBRs

2.2.1. Experimental setup for aerobic SCMBR and SCMPBRs

One 7-L SCMBR was operated at a HRT of 3 h and a solids retention time (SRT) of 20 d to produce enough membrane permeate for three SCMPBRs. Previous work [6] had shown good nutrient removal performance and microalgae growth for flasks cultivated using permeate from membrane bioreactor (MBR) operated at shorter HRT. Furthermore, operating SCMBR at shorter HRT would reduce the combined HRT of both the SCMBR and SCMPBR. The SCMBR was started up with seeding mixed liquor collected from the aeration basin of a local wastewater treatment plant. Domestic wastewater collected from the same plant was pre-filtered with a 1-mm sieve and fed continuously to the SCMBR. The SCMBR was operated for 60 d (i.e., 3 times of SRT) for biomass acclimatization before commencing experiments on the SCMPBRs. To facilitate a meaningful comparison of the performance between each SCMPBRs, the SCMBR permeate produced was fed to a well-mixed equalization tank and distributed to three 7-L SCMPBRs simultaneously to grow *C. vulgaris*. The SCMBR was equipped with two 200-nm pore-sized flat sheet ceramic membrane modules (ITN, German), each with a total membrane surface area of 0.08 m^2, mounted between two baffle plates. Each module was located above a diffuser with an effective aeration rate of 3 L of air per minute per module. The dimensions and the properties of the ceramic membranes are described in Low et al. [7].

The three SCMPBRs are denoted as $SCMPBR_{72h}$, $SCMPBR_{24h}$ and $SCMPBR_{6.5h}$, which referred to the SCMPBR operated at 72-, 24- and 6.5-h HRT, respectively. One membrane module identical with that in the SCMBR was used in each SCMPBR. The SCMBR and SCMPBRs were operated with similar intermittent suction cycle of 8-min on and 2-min off for the relaxation of the membrane. All experiments were performed under ambient condition (26–32 °C) during the entire experimental period. The SCMBR was operated at a pH of 7.2 ± 0.2, controlled using an alkaline-dosing (0.2 M Na_2CO_3) pump. For SCMPBRs, the pH in each reactor was found to be stable