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Research review paper

Membrane technology in microalgae cultivation and harvesting: A review

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ABSTRACT

Membrane processes have long been applied in different stages of microalgae cultivation and processing. These processes include microfiltration, ultrafiltration, dialysis, forward osmosis, membrane contactors and membrane spargers. They are implemented in many combinations, both as a standalone and as a coupled system (in membrane biomass retention photobioreactors (BR-MPBRs) or membrane carbonation photobioreactors (C-MPBRs). To provide sufficient background on these applications, an overview of membrane materials and membrane processes of interest in microalgae cultivation and processing is provided in this work first. Afterwards, discussion about specific aspects of membrane applications in microbial cultivation and harvesting is provided, including membrane fouling. Many of the membrane processes were shown to be promising options in microalgae cultivation. Yet, significant process optimizations are still required when they are applied to enable microalgae biomass bulk production to become competitive as a raw material for biofuel production. Recent developments of the coupled systems (BR-MPBR and C-MPBR) bring significant promises to improve the volumetric productivity of a cultivation system and the efficiency of inorganic carbon capture, respectively.

Contents

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Introduction

The use of microalgae as a source of biofuel raw materials and for wastewater treatment has recently gained enormous research interest. This is due to several reasons: microalgae are able to convert CO_2 into biofuel stocks, as well as food, feeds, and high value products (Chisti, 2007). Some of these microalgae grow extremely fast and can double their biomass within 24 h (Chisti, 2008; de la Noue and de Pauw, 1988). Moreover, they grow throughout the year and can be cultivated and harvested continuously (Chen et al., 2011), they can grow in wastewater to remove nutrients, and so forth. It is worth mentioning that the common cited advantages are based on a poor generalization aimed to serve particular interest in biotechnology (Klein-Marcuschamer et al., 2013). Therefore, careful considerations are required when those advantages are assigned to any microalgae species of interest.

In the overall production process, microalgae are initially grown either in an open pond or in a closed photobioreactor (PBR), to reach a maximum biomass concentration of 0.02–0.5% (Brennan and Owende, 2010). From the culture medium, the biomass is concentrated to 15–20%, either in a single step or in a train of concentration steps, before they can be processed further via drying, extraction and other downstream processing steps (Heasman et al., 2000).

Despite continuous support for research and development on algal biofuel, it is well accepted that many challenges have to be addressed before it can be realized, even to have any hope for replacing >5% of petroleum derived fuels in the USA (Klein-Marcuschamer et al., 2013). The key aspects are: recycling of the inorganic nutrients, recovering the energy from the spent biomass, improving the CO_2 supply as it becomes the main bottlenecks, and reducing the cost of producing algal biomass with an oil content of ≥40% to about $0.25/kg on a dry basis (Chisti, 2013b). Nevertheless, microalgae still have many competitive advantages over other conventional biofuel sources (Chisti, 2008). To meet the key aforementioned challenges of lowering the production costs, substantial developments are still required, especially in the cultivation and harvesting steps (Pienkos and Darzins, 2009; Posten, 2009). A more detailed discussion about constraints of algal fuels commercialization can be found elsewhere (Chisti, 2013a).

Harvesting microalgal biomass is a major challenge because of their small size (typically a few micrometers), their density (almost similar to water) and their low concentration in the culture medium. Thus, the energy inputs to the cultivation/harvesting processes are high, and often exceed the energy content of the microalgal biomass itself (Chisti, 2007; Greenwell et al., 2010; Uduman et al., 2010). Most existing large-scale microalgal plant systems (mostly aimed for production of high value products) still use energy-intensive centrifuges to harvest microalgae. This is economically justifiable because they target high-value end products, such as nutrition supplement and cosmetics (Brennan and Owende, 2010; Molina Grima et al., 2003; Wijffels et al., 2010). Therefore, to be economically attractive for bulk production for biofuel, the production costs of microalgae need to be reduced dramatically (Harun et al., 2010; Tredici, 2010).

In this review, the use of membrane technologies in microalgae cultivation and processing is comprehensively addressed. Different membrane processes have been investigated: microfiltration (MF), ultrafiltration (UF), dialysis and forward osmosis (FO) during the cultivation and harvesting stage; and membrane contactor and membrane sparger during the delivery stage of inorganic carbon into the cultivation medium. To provide sufficient background, a brief review about basic materials and operation of the aforementioned membrane processes is firstly provided. Afterward, different aspects of membrane technology in microbial cultivation and harvesting are thoroughly discussed.

Fundamentals of relevant membrane processes

A membrane is defined as a “selective barrier between two phases” that is used to perform a separation under the influence of a driving force (Fig. 1) (Baker, 2000; Mulder, 1996). The driving force can be pressure, concentration, temperature, etc. To be applicable for a filtration process, a bundle of membrane fibers or a multi-sheet set is assembled into a module. A module is consist of a number of membrane elements. The typical membrane modules for pressure driven membrane

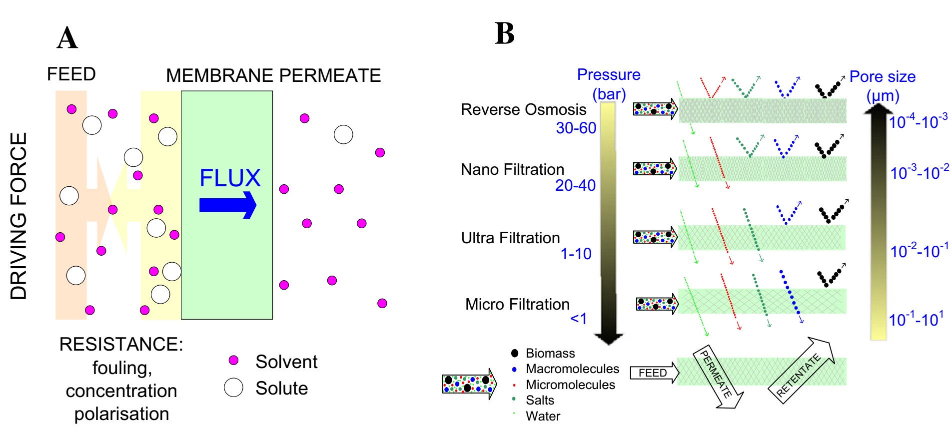

Fig. 1. (A) Basic scheme of a membrane filtration process and (B) schematic illustration of different solute rejections in pressure driven membrane processes.