New phototrophic biofilm reactor with an integrated membrane CO_2 contactor applied to municipal wastewater treatment

Bagnoud-Velásquez, M.[1]*, Hu, J.[1], Mahmed, C.[1], Michel, J-B.[1]

[1]University of Applied Sciences and Arts Western Switzerland, Thermal Engineering Institute, Industrial Bioenergy Systems unit, HEIG-VD, Centre St-Roch, Avenue des sports 20, 1401 Yverdon-les-Bains, Switzerland.

*Corresponding author: mariluz.bagnoud@heig-vd.ch; tel. +41 24 557 61 41.

The main obstacles to using microalgae as a tool for municipal wastewater treatment are the low concentrations of N and P in the water, combined with the significant carbon demand to support highly productive, stable and effective phototrophic systems. The volumetric biomass density will thus tend to be low for suspended growth cultures. In nutrient limited conditions, biofilms can achieve high biomass density and consequently are a recommended alternative to suspended cultures. However, to achieve successful wastewater treatment, there is still the need to supply adequate amounts of dissolved CO_2 to the cells and to remove waste gases to the atmosphere at minimum energy cost. Usually, researchers neglect to study CO_2 dissolution and meet this requirement via air bubbles which is an inefficient process. In order to address these concerns, we have developed a new phototrophic biofilm reactor with an integrated membrane CO_2 contactor absorber. The new system not only provides a large gas-liquid surface area for mass transfer but also optimizes the photosynthetic efficiency of the biofilm. Indeed, the location of the biofilm as a permeable barrier between the liquid phase and the gaseous phase is optimal. Phototrophic biofilm growth is promoted thanks to the maintenance of the liquid-gas interface as described by biofouling theories. On the other hand, the CO_2 molecule can also reach the cells more efficiently by diffusing into them thanks to a very low resistance to the gas-solid mass transfer. Our CO_2 absorption system has two compartments: 1) an internal compartment where the very low pressure CO_2 rich gas is distributed in a confined honeycomb structure and 2) an external compartment which is essentially a gravity-laminar countercurrent flow of wastewater containing nutrients. The compartments are separated by a microporous membrane supporting the phototrophic biofilm. The CO_2 rich gas is forced to cross the biofilm to meet the water barrier and in doing so supplies CO_2 to the algal biofilm.

We have demonstrated the efficiency of our CO_2 absorption system by a relatively high surface biomass yield of 6,2 g m^{-2} day^{-1}. According to a review by Gross and colleagues [1], most of the reported surface biomass productivities for algal biofilm reactors range between 2 and 6 g m^{-2} day^{-1}. The advantages of the membrane contactor are many, ranging from the elimination of the problem of phase dispersion to the possibility of exchanging gas at near atmospheric pressure, allowing easy installation and low cost for these systems. The integration of this new CO_2 contactor packed into the phototrophic biofilm reactor with CO_2 diffusing from the interior (while light and nutrients from the exterior) constitutes an innovation that has not, to our knowledge, been reported previously.

[1] Gross M, Jarboe D, Wen Z. Biofilm-based algal cultivation systems. Appl Microbiol Biotechnol. 2015; 99(14):5781–5789.