Assessing the impact of physical and physiological factors on the oxygen mass transfer process in membrane-aerated biofilm reactors

Pellicer i Nàcher, Carles; Syron, E.; Gaval, G.; Ochoa, J.; Smets, Barth F.

Publication date:
2011

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Pellicer i Nàcher, C., Syron, E., Gaval, G., Ochoa, J., & Smets, B. F. (2011). Assessing the impact of physical and physiological factors on the oxygen mass transfer process in membrane-aerated biofilm reactors. Poster session presented at Specialist Conference on Membrane Technology for Water & Wastewater Treatment, Eurogress Aachen, Germany, .

Assessing the impact of physical and physiological factors on the oxygen mass transfer rates in membrane-aerated biofilm reactors

DTU Environment
Department of Environmental Engineering

Carles Pellicer-Nàcher[1], Boris Roth [1], Gilberte Gaval[2], Juan Ochoa[2], Barth F. Smets[1]

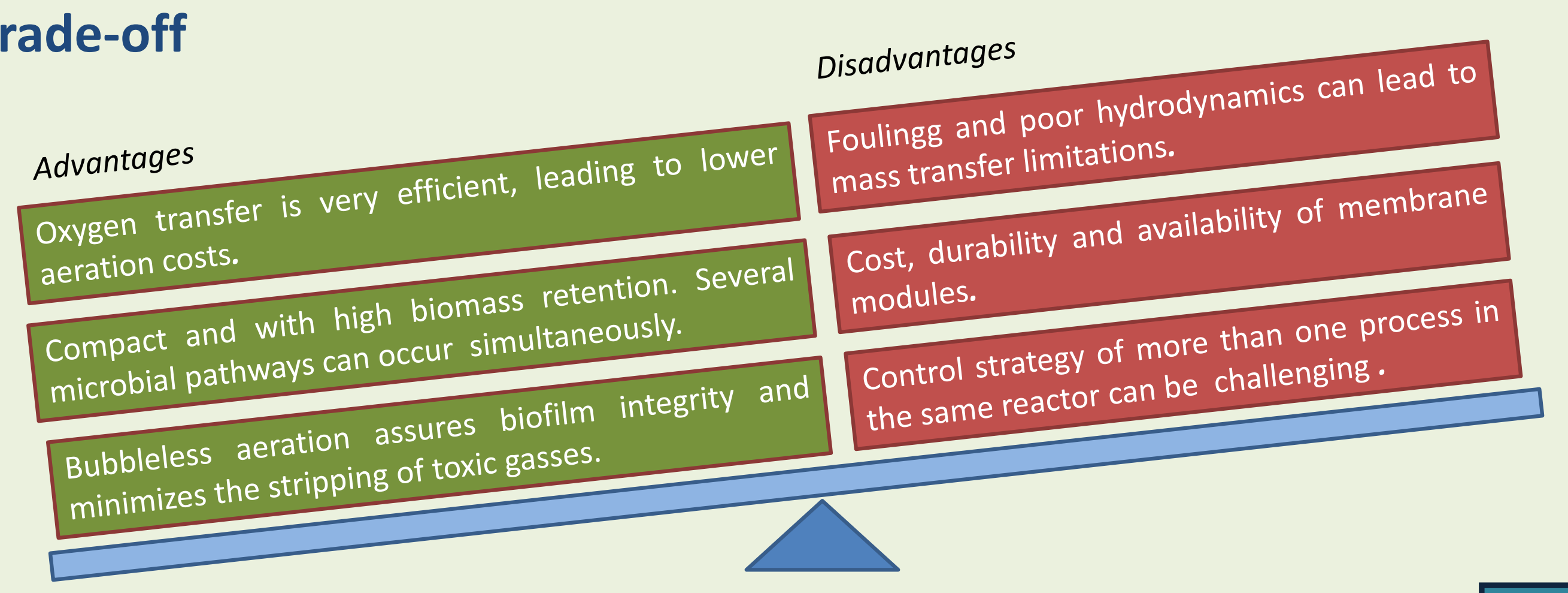
[1] Department of Environmental Engineering, Technical University of Denmark; [2] Pôle Biotechnologies et Agronomie Veolia Environment Research and Innovation, Maisons – Laffitte, France.

E-mail: capn@env.dtu.dk

1. Introduction

Membrane-aerated biofilm reactors (MABRs) are systems where an air/oxygen stream diffuses through a membrane, which is submerged in wastewater and which also serves as the substratum for biofilm growth. The counter-diffusion of nutrients within the biofilm matrix creates unique niches for the co-existence of distinct microbes.

Trade-off



Advantages

- Oxygen transfer is very efficient, leading to lower aeration costs.
- Compact and with high biomass retention. Several microbial pathways can occur simultaneously.
- Bubbleless aeration assures biofilm integrity and minimizes the stripping of toxic gasses.

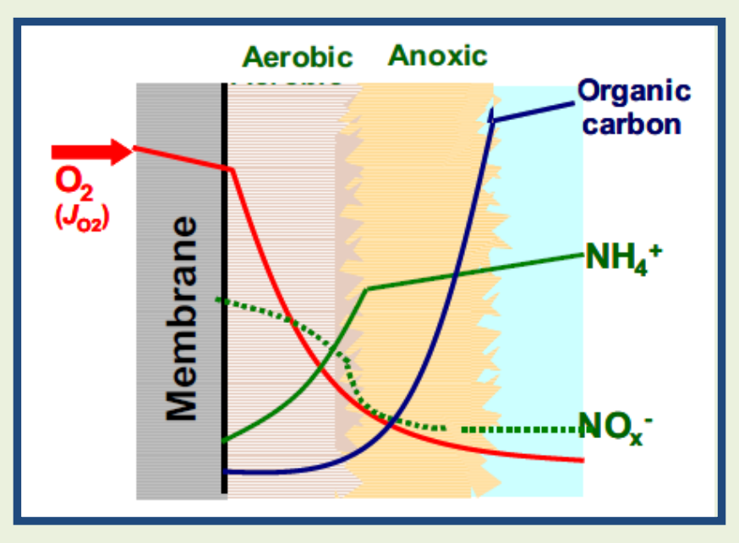
Disadvantages

- Foulingg and poor hydrodynamics can lead to mass transfer limitations.
- Cost, durability and availability of membrane modules.
- Control strategy of more than one process in the same reactor can be challenging .

Flexibility

- P removal
- Nitritation-Anammox
- Xenobiotic removal
- Nitrification-denitrification

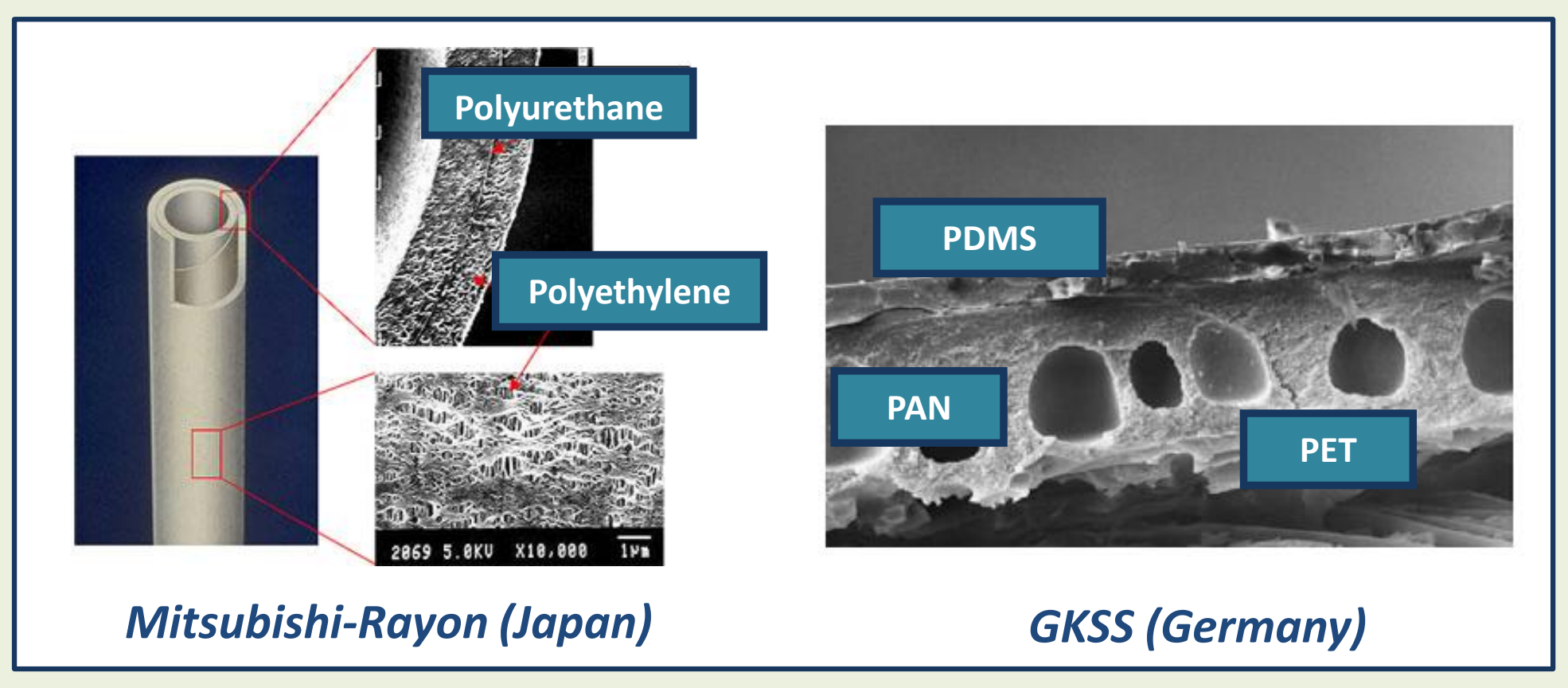
Application example



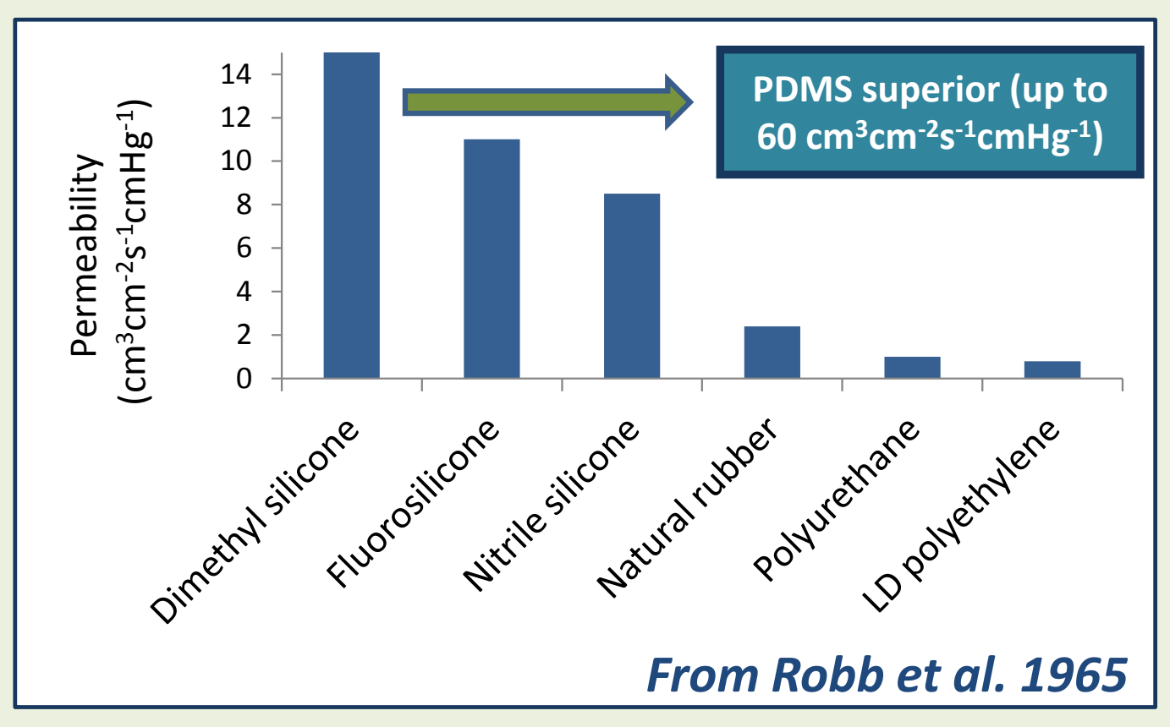
MABRs can be used for simultaneous nitrification-denitrification of wastewaters. After reactor innoculation a layered biofilm develops. Nitrifying bacteria convert the incomming ammonium to nitrite and nitrate in the first 100-200 mm by using the oxygen diffusing from the membrane surface. The produced nitrogen can be denitrified by heterotrophic bacteria in the upper anoxic biofilm region by using the organic carbon present in the wastewater as electron donor.

2. Reactors / membranes

A wide range of hydrophobic materials have been used that can support biofilm development. Composite membranes are preferred because of their superior mechanical stability and oxygen transfer capabilities.

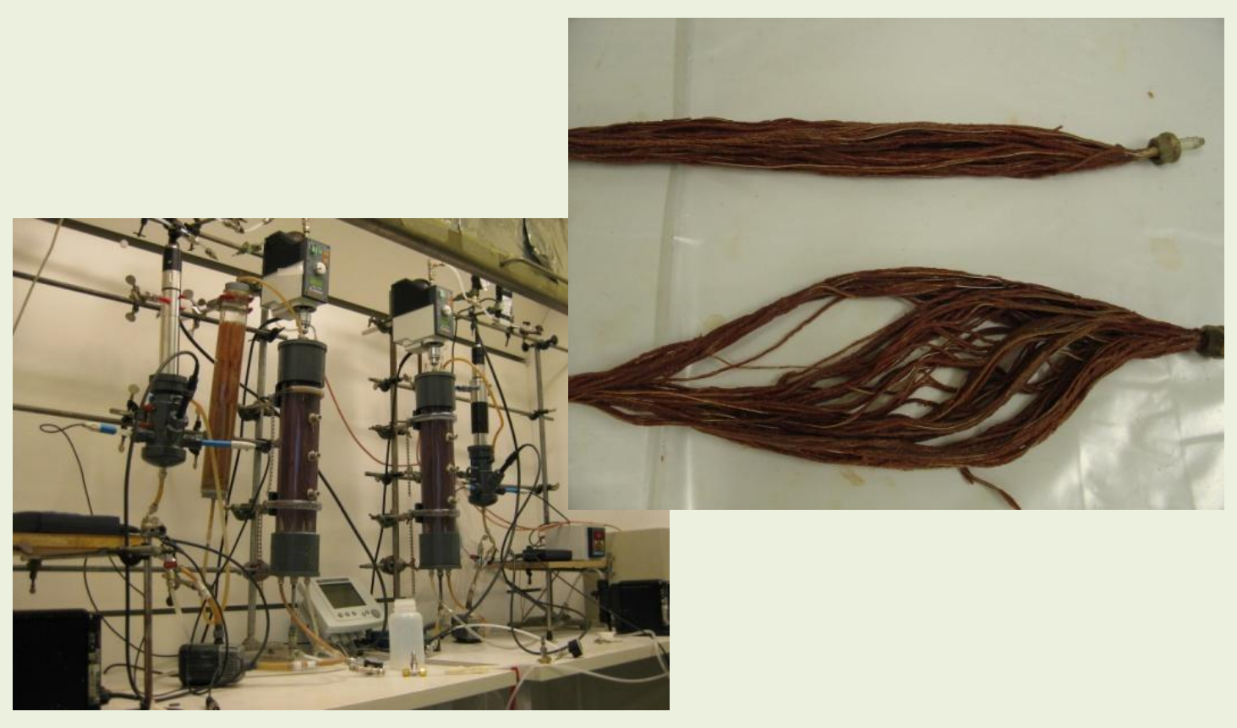


Mitsubishi-Rayon (Japan)　*GKSS (Germany)*

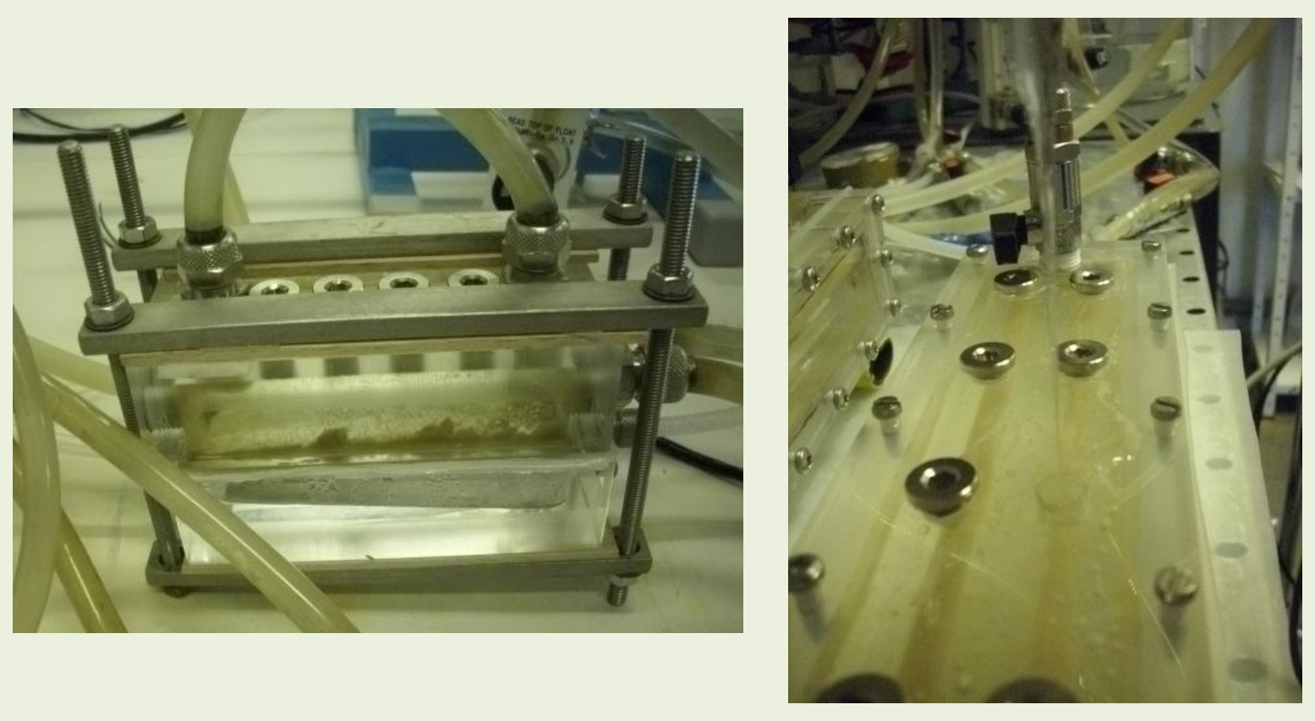


From Robb et al. 1965

Membranes are arranged in modules in order to satisfy research/application needs.



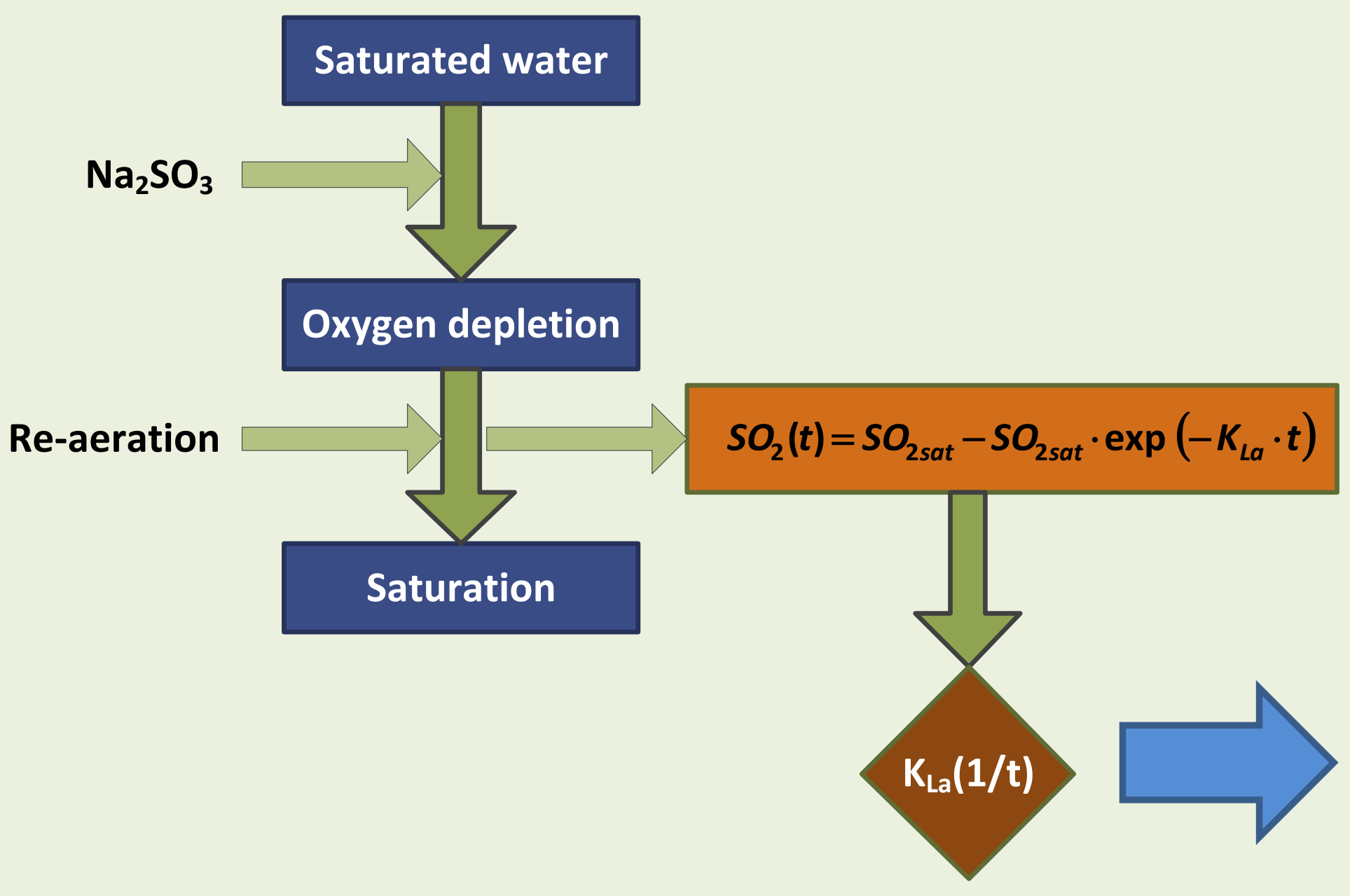
High specific surface areas



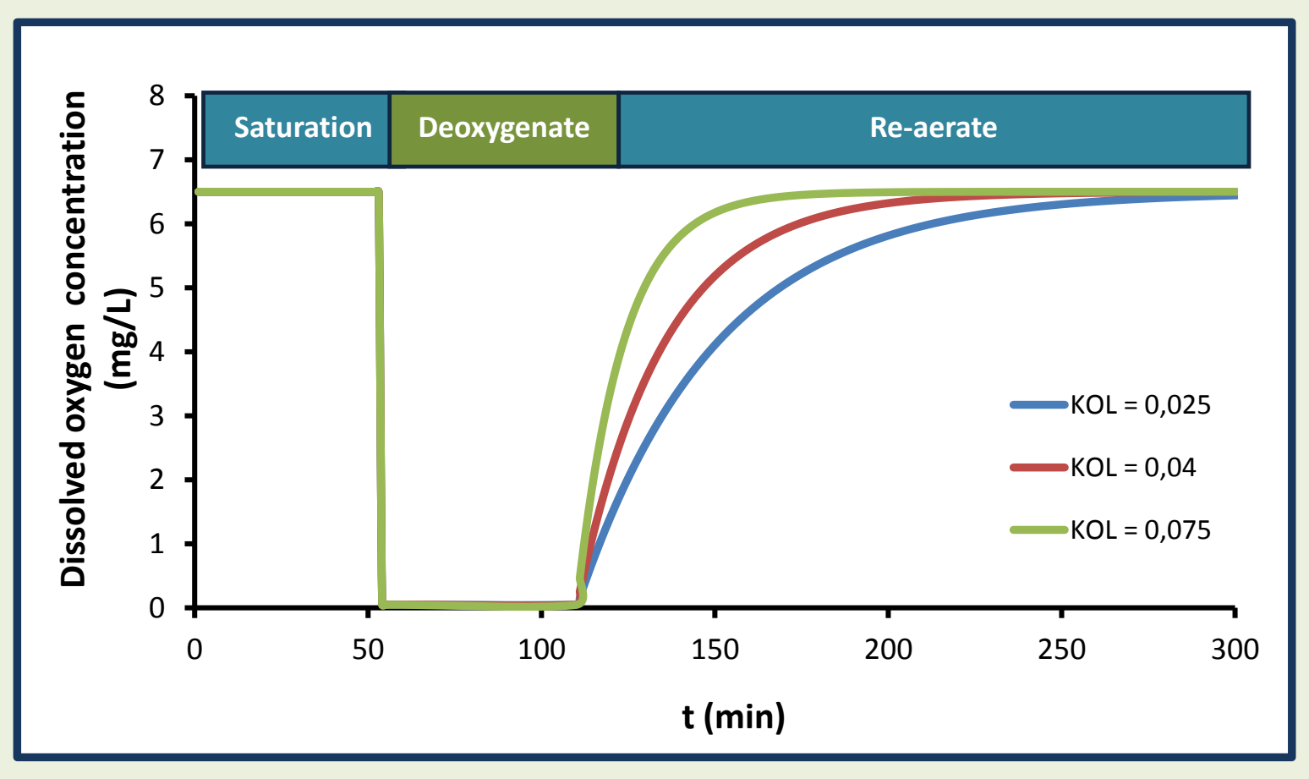
Easy inspection and sampling

3. Oxygen transfer characterization in MABRs

The oxygen transfer capabilities of a certain membrane/reactor system is quantified by standard oxygen transfer tests in clean water.



$$SO_2(t) = SO_{2sat} - SO_{2sat} \cdot \exp\left(-K_{La} \cdot t\right)$$



$$OTR\left(\frac{g-O_2}{m^2 \cdot day}\right) = \frac{dSO_2}{dt} \cdot \frac{1}{a} = \frac{K_{La}}{a} \cdot \left(\frac{SO_2|_{lumen}}{H} - SO_2|_{BulkLiquid}\right)$$

$$OTR = K_{OL} \cdot \left(\frac{SO_2|_{lumen}}{H} - SO_2|_{BulkLiquid}\right) \qquad SO_2|_{lumen} = \frac{y_{O2} \cdot P_T}{R \cdot T} \cdot MW_{O2}$$

Where...

OTR: Oxygen transfer rate (g-O_2/m^2/day)
S_{O2}: Oxygen concentration (g/m^3)
K_{La}: Overall film coefficient (1/day)
K_{OL}: Overall mass transfer coefficient (m/day)
a: Specific surface area (m^2/m^3)

H: Henry coefficient (unitless)
y_{O2}: mass fraction of O_2 in air
P_T: Total pressure in the lumen (atm)
R: ideal gas constant (8.31 atm·m^3/K/mol)
T: Temperature (K)
MW_{O2}: Molecular weight of O_2 (g/mol)

However...

Observed OTR s with biofilm >> measured OTR in clean water -> Why?

We make use of the interfacial mass transfer theory to understand the oxygen transfer in these systems

Considering that no oxygen reacts we can write:

$$OTR = K_{OL} \cdot \left(\frac{SO_2|_{lumen}}{H} - SO_2|_{BulkLiquid}\right) = J_{O2,1} = J_{O2,1}$$

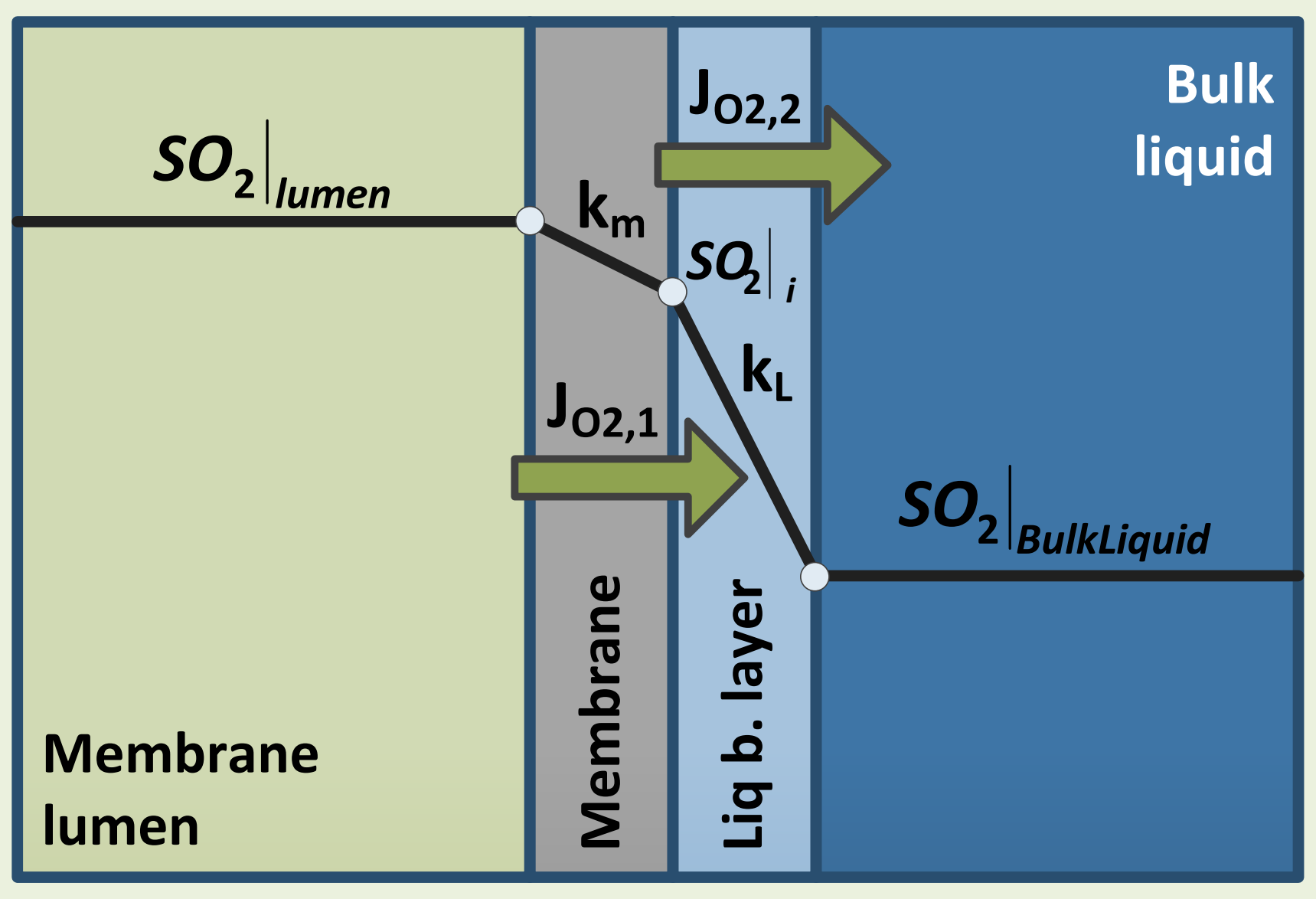
$$OTR = k_m \cdot \Delta S_m = k_L \cdot \Delta S_L$$

Where ΔS_m, ΔS_L, k_m and k_L are the oxygen concentration drops and the individual oxygen mass transfer coefficients through the membrane and the liquid boundary layer.

These coefficients are related with K_{OL} as follows:

$$\frac{1}{K_{OL}} = \frac{1}{k_m} + \frac{1}{k_L}$$

$$J_{O2,2} = k_L \cdot \left(SO_2|_i - SO_2|_{BulkLiquid}\right)$$



$$J_{O2,1} = k_m \cdot \left(\frac{SO_2|_{Lumen}}{H} - SO_2|_i\right)$$

Therefore...

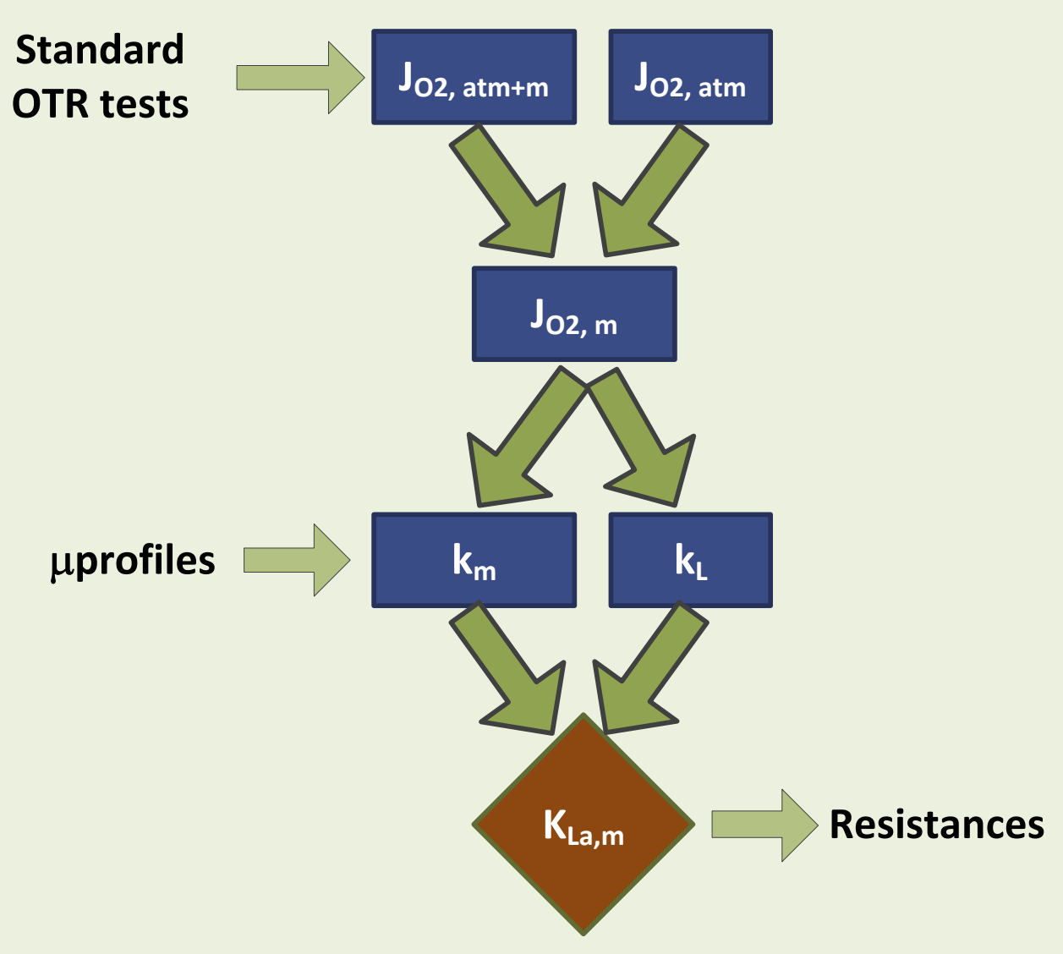
Can we use of microelectrodes measurements to better estimate the overall mass transfer coefficient that describes the oxygen transfer when a biofilm develops on top of the membrane?

How can we make even more efficient oxygen transfers in MABRs?

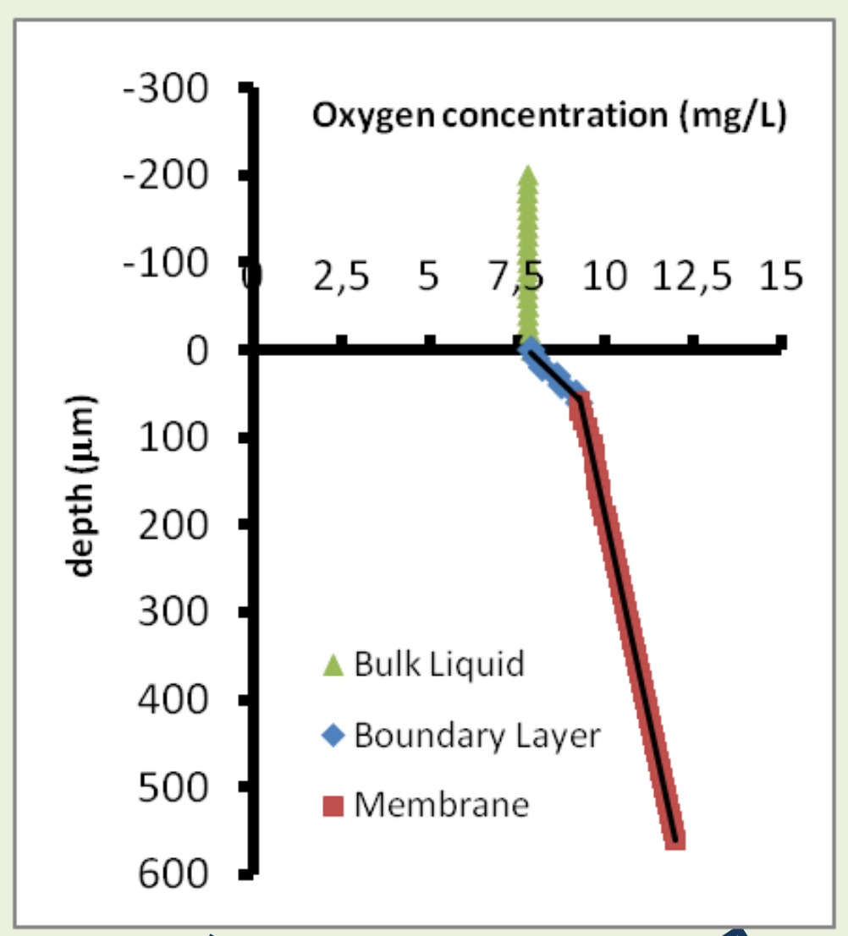
4. Microelectrode investigations

An MABR equipped with 2 silicone hollow-fiber membranes and a specific surface area of 14 1/m was used. An O_2 microelectrode (OX10, Unisense, Denmark) was mounted in a micromanipulator; O_2 profiles were measured in 10 µm increments. O_2 concentrations in the bulk liquid were measured by a polarographic O_2 sensor (CellOx325, WTW, Germany) placed in the recirculation line. Tests were done in clean water.

Method



Result



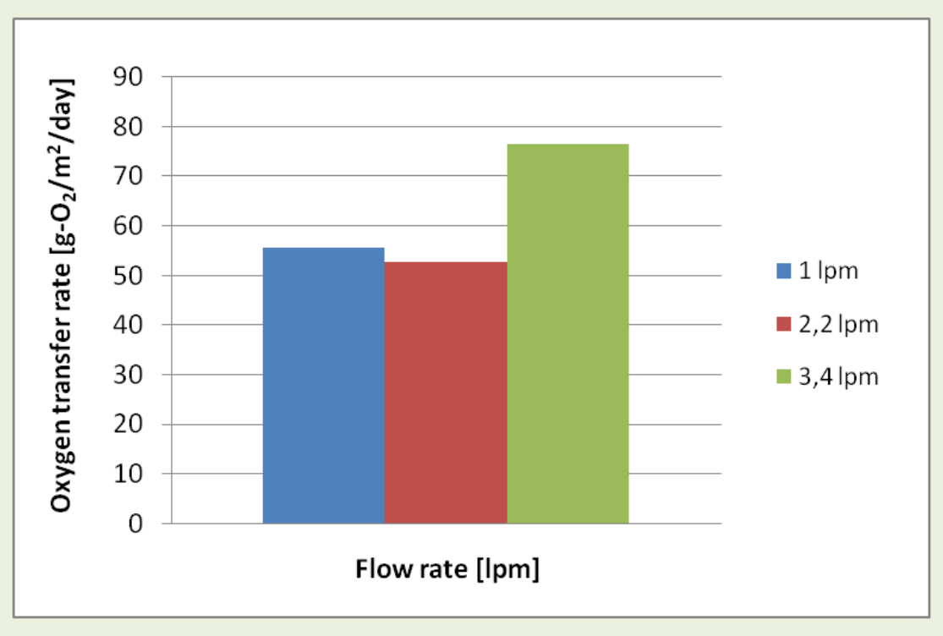
Assuming that biofilm development removes BL resistance, yields an increase of the K_{OL} of about 50%. This increase matches previous experimental observations (Lackner et al. 2010)

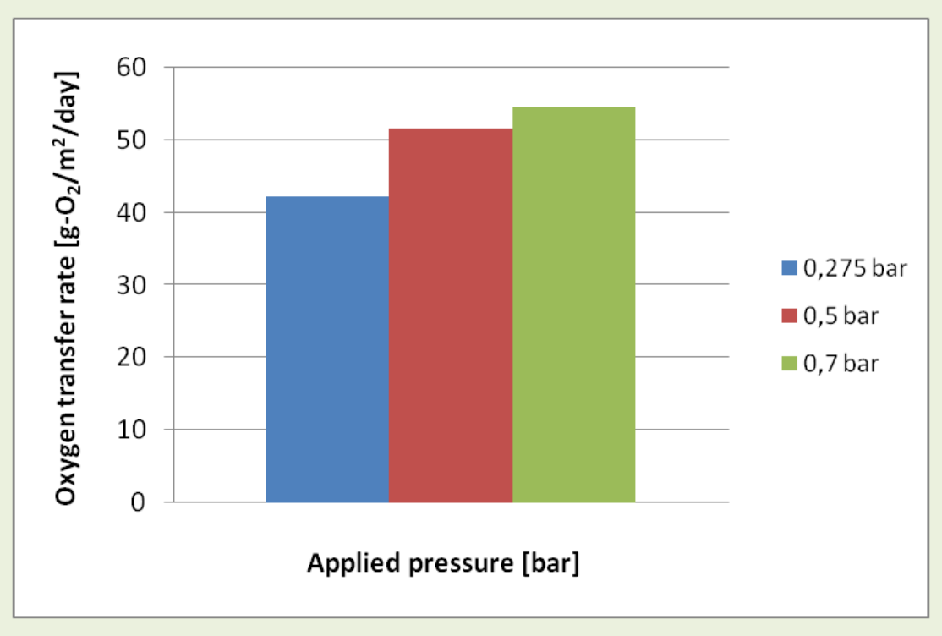
Microprofiles identified the different gradient areas

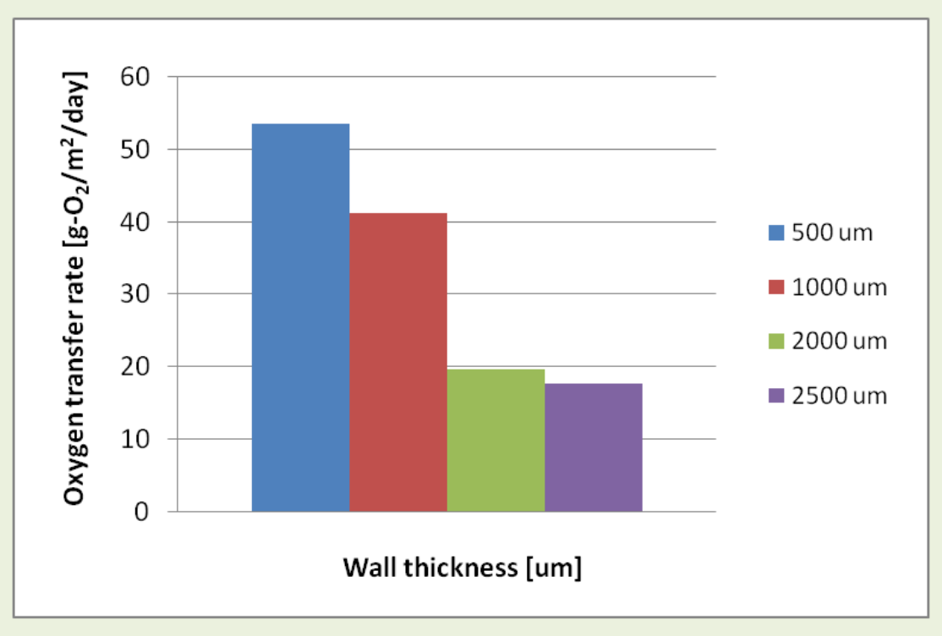
Liquid boundary layer yields the highest resistance per unit length in the system

5. Optimization/Outlook

Our investigations confirmed that increases in the lumen pressure and the recirculation flow rates in the flow cells enhanced the oxygen transfer rates up to 80 g-O_2/m^2/day due to increases in the concentration gradient and reductions in the thickness of the liquid boundary layer. Hollow fiber membranes with thinner walls also tend to supply oxygen faster due to their lower mass transfer resistance.







Overall:

- **MABRs are excellent tools for more sustainable and efficient wastewater treatment.**
- **Microelectode inspection allow for an accurate estimation of the individual mass transfer coefficients involved in the transfer of oxygen through MABRs without the use of mis-leading correlations.**
- **The interfacial mass transfer theory properly describes the increase in OTR with respect to the clean water tests once biofilm develops on the membrane. Biochemical reactions are not expected to have a significant effect on OTR.**
- **Our findings allow for more detailed and precise MABR models .**

***This project was economically supported by VEOLIA Environnement Research Institute, France.*