Electroactive biofilm development under controlled hydrodynamic in a Couette-Taylor electrochemical reactor

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The activated sludge process is the most commonly used to remove organic matter from wastewater. It requires blowing air into aerated tanks to promote microbial growth thus ensuring efficient removal of pollutants. However, aeration is one the largest energy consumers in wastewater treatment plants (70% of the total power consumption of the facility). To reduce oxygen supply, an innovative bioelectrochemical system (BES) is considered using an electrochemical snorkel. The microbial anode is one of the key components of BES since it allows empowering the system by producing electrons. However, the influence of the hydrodynamics on the electroactive biofilm (EAB) formation and development is still not fully understood. In particular, its influence on microbial diversity, electrochemical activity and biofilm structural properties has not been studied in depth. To address those bottlenecks, the first electrochemical Couette-Taylor reactor (eCTR) was designed to study the shear stress impact on the EAB performances.

The eCTR contains 20 planar graphite electrodes included in the rotating inner cylinder. Those electrodes serve as support for the biofilm growth; while, a stainless steel outer cylinder is used as abiotic cathode. Primary effluent from a sewage treatment plant was supplemented with acetate and used as electron donor in continuous feeding. Microbial electrodes were characterized electrochemically. Physico-chemical parameters (COD, pH, conductivity, [O_2]) were measured and controlled in the reactor. The microbial diversity is characterized by sequencing 16S rDNA ribotags. Their structural properties are analysed by tomography and the expressed functions by sequencing cDNA in shotgun metatranscriptomics.

Experiments were first conducted in abiotic conditions with a hexacyanoferrate (III/II) electrolyte to precisely characterize the reactor electrochemical response under different hydrodynamic regimes. Results showed a transition domain for a rotation speed of the inner cylinder of 8 RPM, which corresponded to a shear stress of 50 mPa on the surface of the electrodes. This value is correlated to the separation between the wavy vortex and turbulent vortex flow in Couette-Taylor. To quantify the impact of the hydrodynamic conditions on electrochemical reactions, the diffusive layer thickness (δ) was calculated. Its value depended on the angular velocity (ω) and to the flow regime according to $\delta \propto \omega^{-\alpha}$ with α = 0.4 for the wavy vortex and α = 0.6 for the turbulent vortex flow.

Bioanodes were then formed in real wastewater under constant polarization and wavy vortex flow, with performances perfectly reproducible. Maximum current density of 3.75 A/m² was reached after 10 days corresponding to a removal rate of 17 gCOD/m²/d i.e. a coulombic efficiency that ranged between 22 and 30 % for 3 months. Each bioanode was maintained for more than 6 months to study the impact of different hydrodynamic conditions resulting in shear stress from 25 mPa to 10 Pa. First results showed a short-term impact of increasing shear stress on the microbial activity; whereas, the long-term dynamics of the activity appears to be correlated with several operating parameters.

The discussion will show how these results can then be used to monitor EAB activity in urban wastewater treatment strategies at pilot-scale.

Key words: Electroactive biofilms – Bioelectrochemical Taylor-Couette reactor – Shear stress

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