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A LOCAL IMPEDANCE NEEDLE-PROBE FOR BIOFILM THICKNESS MEASUREMENTS

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INTRODUCTION

Biofilm and liquid phase thickness, and the location of the related interfaces are essential parameters in both theoretical studies and practical application of biofiltration systems due to its important role in mass transfer processes. These processes are directly related to diffusion, biofilm formation and detachment phenomena.

At laboratory scale, studies of biofilms behaviour can be carried out, for instance, in flat plate bioreactors (FPB), as it can be seen in Figure 1. In these sense, Guimerà et al. (2015) studied mass transport and biodegradation processes inside biofilms using microsensors designed *ad hoc* (Figure 2), obtaining dissolved oxygen profiles in both the liquid and biofilm phases. Later, these profiles were used to roughly estimate the position of the interfaces between the phases. Therefore, to increase accuracy in biofiltration systems modelling of gas-phase biofiltration, more quantitative experimental information about phases' thickness and interfaces location is highly desirable.

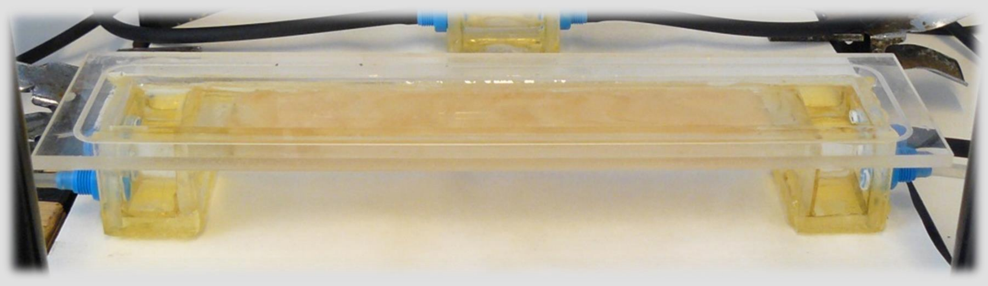

Fig. 1. Details of flat plate bioreactor.

Biofilm and liquid phase thickness measurement should be optimally obtained in situ without influencing the sample. In this sense, methods based on optical and laser technologies have been used to measure biofilm thickness in biofiltration systems (Denkhaus et al., 2007).

These are also non-destructive techniques but their applicability to practical situations is rather limited (i.e. medium opacity, complex instrumentation, etc.). On the other hand, impedance sensors have been used in other fields to measure and detect film layers, due to their simple structure, well dynamic response and high-sensitivity.

In this study, **a needle-probe sensor based on local impedance was developed to measure the thickness of biofilm and liquid phase** inside a heterotrophic biofilm simulating a gas phase biotrickling filter.

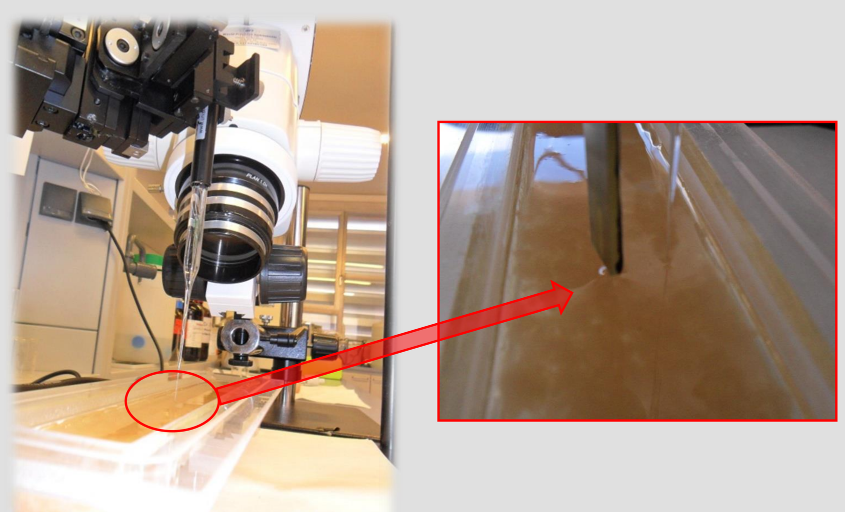

Fig. 2. Profiles measurements using microsensors.

SENSOR DEVELOPMENT

The **developed system** consists of **a two-needle probe and a dedicated electronics** to measure and to process the sine wave signal from a signal generator affected by the medium between electrodes (Figure 3). The **goal** is to **observe the variation in the signal amplitude** (DC value) **due to changes in the medium**, which is modeled as a parallel capacitor and resistance, Cm and Rm respectively.

The probe itself is built in a double coaxial geometry. **Two Ø0,1 mm electrodes** (excitation and measuring electrode, EE and EM respectively) **are insulated except the tip. The zone between the tips will be the active measuring region.**

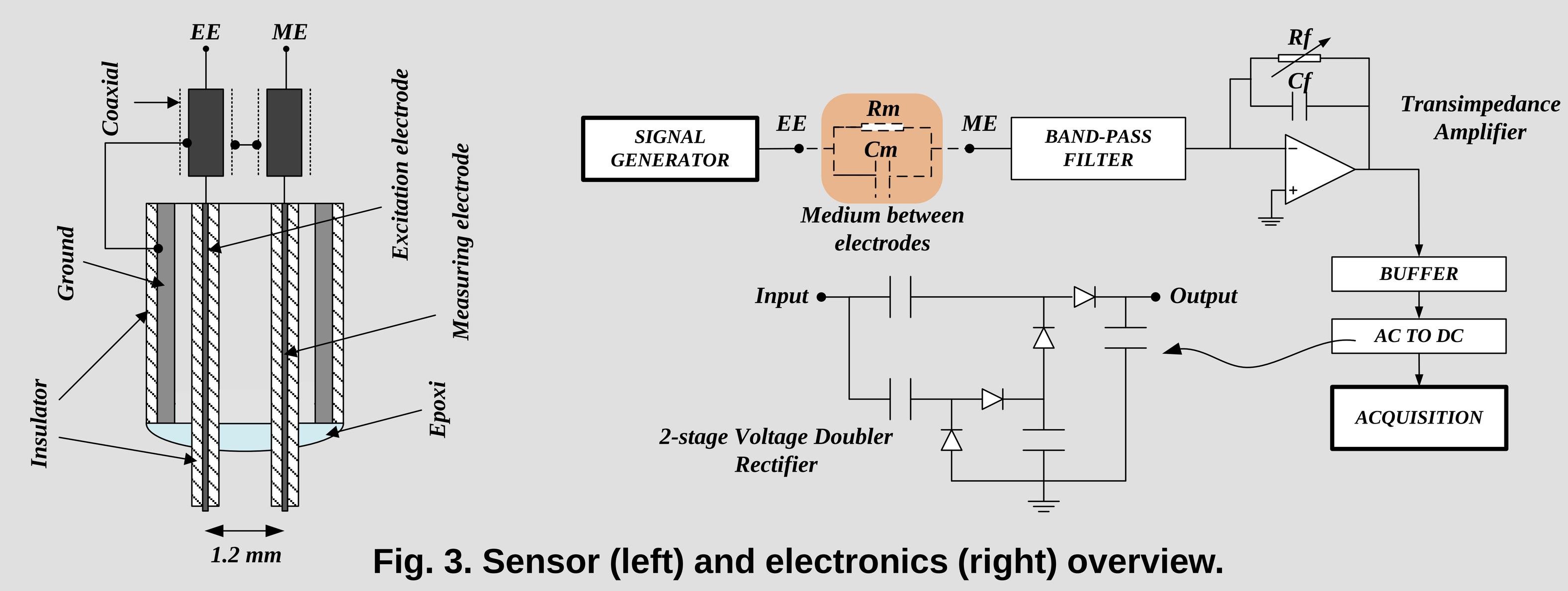

Fig. 3. Sensor (left) and electronics (right) overview.

The **principle of operation** is as follows:

Sine wave generated by a function generator (150 kHz) **passes through the medium** (liquid phase, biofilm-layer or biofilm) **from EE to EM**.

Obtained signal is filtered (band-pass filter) and **passes through a transimpedance amplifier** (circuit stray capacitances immunity and signal amplification).

The **last signal conditioning step** is an **OpAmp buffering stage and a passive RF rectifier** (two-stage voltage doubler rectifier).

Finally, **circuit DC output** is **acquired using acquisition board** NI-USB-6210 **at 100 kHz sampling frequency**.

The **amplitude of sine** wave measured by ME **will be affected by the medium**.

Rf is selected **according to liquid phase conductivity** to improve measurements accuracy.

The **main advantages** of **this rectifier configuration** are: (1) permit to **obtain** a representative **DC value** of the measured sine wave, (2) allow to **work only** with **passive components** and (3) can **operate at RF frequencies**.

RESULTS AND DISCUSSION

In the present study, the needle-probes were mounted on an automatized micromanipulator with a precision of 10 µm. Then, in a section of the flat plate bioreactor, the sensor was positioned at different axial locations of the phases (from gas phase to support), and were placed normal to the bed, obtaining at each position a voltage value relative to the present phase.

Figure 4 shows a profile recorded when placing the probe from the gas to the biofilm phases. The **origin position on the X axis is located in the gas-liquid interface**, where there is a significant step in the voltage signal (non-conductive to conductive phases). Then, when the **sensor is inside the liquid phase, a linear region of voltage profile with slight slope is detected**. Finally, **another linear region of voltage profile with a larger slope** is observed, assuming to be **inside the biofilm**.

The boundary layer thickness is defined as the distance of the profile between the linear parts. Thus, **the estimated liquid-biofilm interface the intersection point between the two regions, which is pointed out with a triangle geometry (Δ)**. It should be noted this point is inside the dashed box, which defines the observed liquid-biofilm interface region.

Therefore, **the thickness of liquid and biofilm phases can be calculated from the experimental data**.

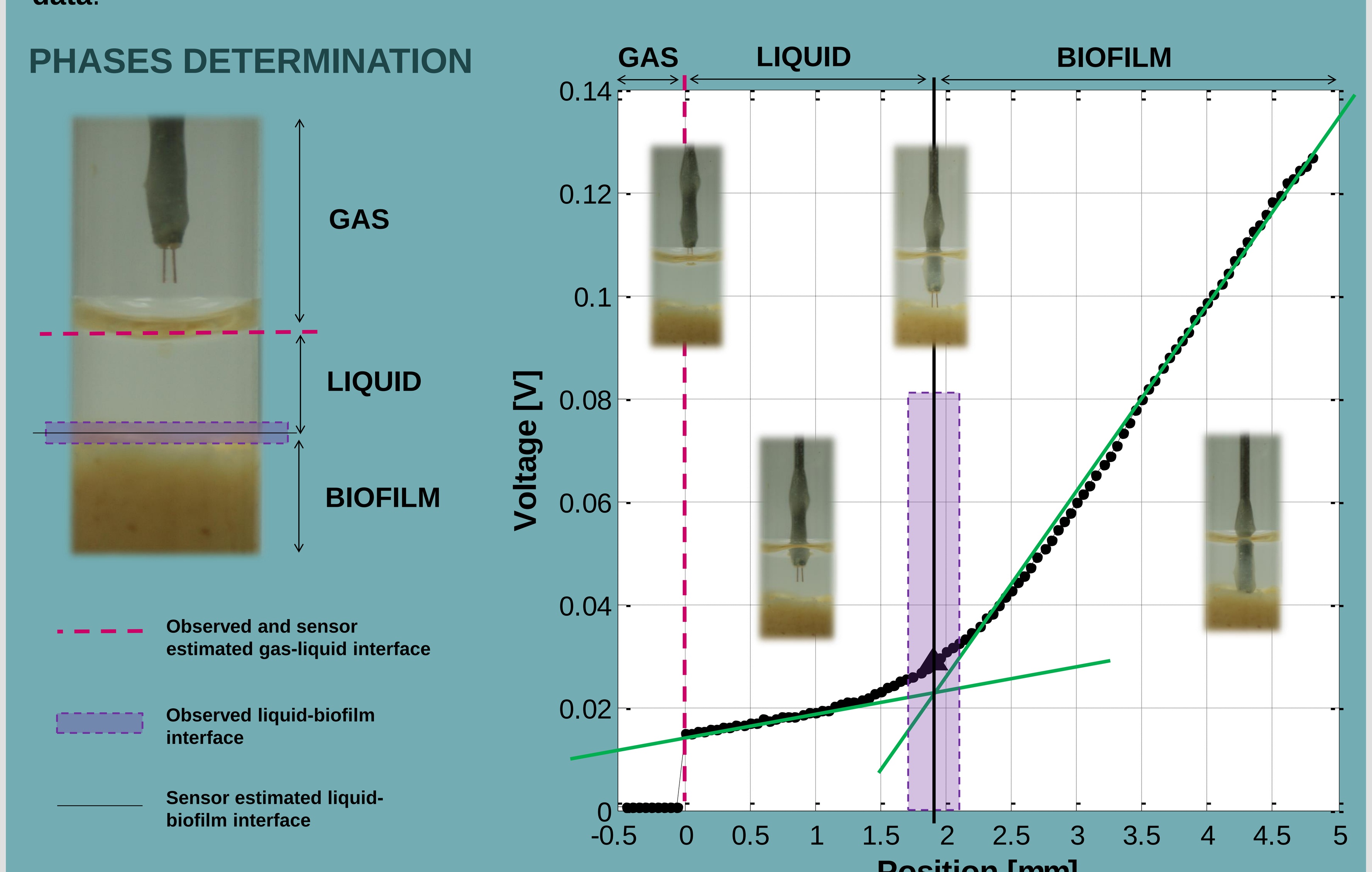

Fig. 4. Explanation of phases (gas-liquid–biofilm) determination.

Figure 5 shows the **analysis of sensor repeatability**. The profile was recorded three times at the same location in the bioreactor, maintaining the same conditions in the liquid phase (conductivity of 50 µS). These profiles follow the same trend for each different phase. Figure 6 depicts four **experiments** in which **the thickness of the liquid layer is different** for each of them. As it can be seen, the sensor detected liquid-biofilm (L-B) interface inside the observed L-B interface for all the experiments which has been carried out.

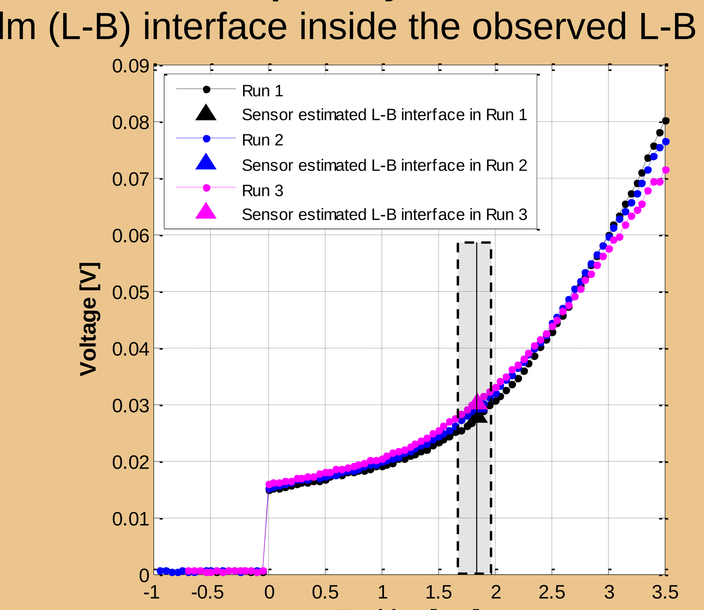

Fig. 5. Sensor repeatability analysis.

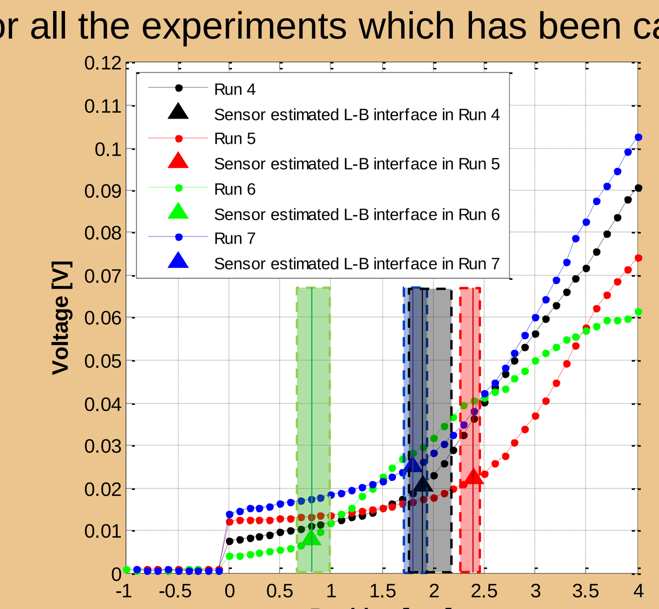

Fig. 6. Profiles with different liquid phase thickness.

Figure 7 shows the **analysis of sensor repeatability in a liquid phase more conductive** (400 µS) than in Figures 5 and 6 (50µS). In this case, the recorded profiles present the same behaviour as in the previous cases. Then, the sensor works correctly in the studied conductivity range. Finally, Figure 8 shows **error dispersion in the acquisition of experimental data** points. In each point the signal was acquired during 1 second at 1000 samples per second, obtaining slight dispersion during all the experiments.

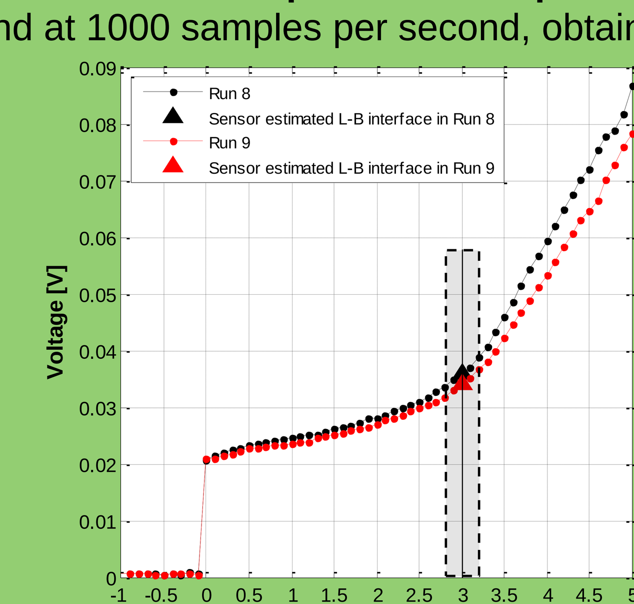

Fig. 7. Profiles at high conductive media.

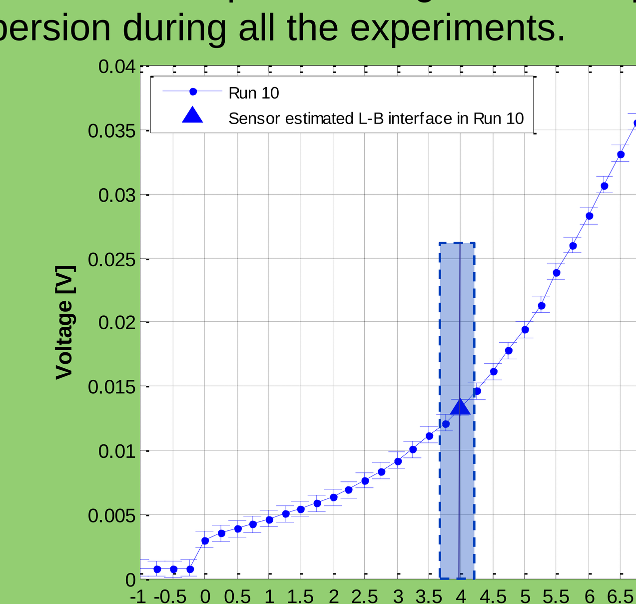

Fig. 8. Acquisition error dispersion.

CONCLUSIONS

The **proposed electronics** with not arduous implementation **has proven its suitability to provide robust and consistent measurements for biofilm layer detection in a multiphase system**. Experimental data demonstrated **this sensor can measure minimal change of impedance with high precision**, obtaining accurate measurements with the presence of a liquid layer upon the biofilm.

Therefore, **the developed sensor can be placed virtually anywhere within the medium with minimum invasiveness due to their small size**, **allowing in situ and real time measurements of the interfaces and the thickness of the phases (liquid and biofilm)**. In addition, this sensor can be also used in anaerobic systems, where dissolved oxygen profiles cannot be obtained.

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