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Development of an automation system to evaluate the three-dimensional oxygen distribution in wastewater biofilms using microsensors

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Abstract

In this paper the authors describe the development of an automation system applicable to environmental biofilm studies. The automation system controls a combined oxygen microsensor to measure the three-dimensional dissolved oxygen distribution in a wastewater biofilm sample. The biofilm is sampled from a rotating biological contactor in a municipal wastewater treatment plant. The automation system consists of a data acquisition system, a motion control system, and a computer program. The combined oxygen microsensor consists of a sensing electrode, a reference electrode, a guard cathode, an oxygen permeable membrane, and an electrolyte solution. The automation system allows the acquisition and storage of data from 4000 measurements from the microsensor and the precise positioning of the microsensor in order to measure 100 dissolved oxygen profiles in a 1000 μm × 1000 μm biofilm area. The three-dimensional profile shows that the dissolved oxygen concentration in the biofilm sample is highly heterogeneous and it revealed "pockets" of dissolved oxygen in deep sections of the biofilm sample. The automation system and the combined oxygen microsensor were proven to be tools that improve the quantity and quality of experimental results needed to understand important functions in biofilms used in wastewater treatment.

Keywords: Automation; Microsensor; Microelectrode; Oxygen; Three-dimensional; Biofilm; Wastewater; Environmental

1. Introduction

Biofilms are widely used in the treatment of industrial and municipal wastewater. A biofilm can be defined as a group of living cells, dead cells and cell debris in a matrix of extracellular polymeric substances attached to a surface [2]. Understanding the complex operation of biofilms is essential for the optimization of biofilm reactor design and operation. Different microsensors have been used as powerful tools to evaluate different parameters, such as oxygen, pH, redox potential, ammonium and sulfide in biofilms [1,3,6,12,14,16,17].

One-dimensional dissolved oxygen profiles measured using oxygen microsensors have always shown that oxygen is depleted at about 200–800 μm depth in the biofilms [1,6,16]. In order to evaluate the biofilm heterogeneity in terms of oxygen, it is necessary to map the three-dimensional dissolved oxygen distribution in biofilms. This can be achieved by measuring many dissolved oxygen profiles in a specific biofilm section. Due to the heterogeneous nature of biofilms, the three-dimensional dissolved oxygen distribution could show functional and structural characteristics that might not be observed with the typical one-dimensional dissolved oxygen profiles. The data generated can be incorporated in biofilm models that evaluate the importance of the three-dimensional heterogeneity of oxygen in biofilms [5,10,11,13].

The amount of data needed to map the three-dimensional dissolved oxygen distribution in biofilms using oxygen microsensors requires the development of an automation system that allow precise microsensor positioning and the recording of large quantities of data.

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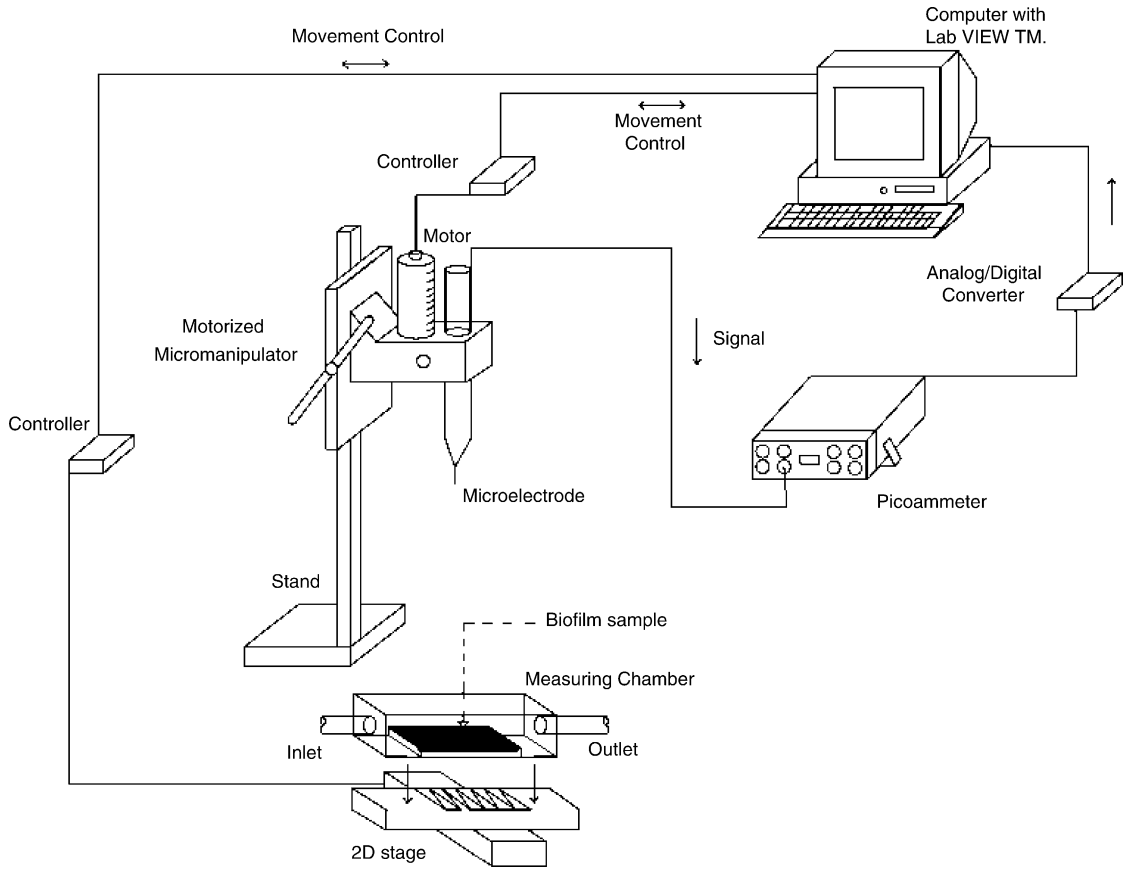

Fig. 1. Components and connections of the automation system.

2. Experimental

2.1. Automation system

The automation system consisted of three parts: a data acquisition system, a motion control system, and a computer program. In Fig. 1, a schematic diagram showing all the components and connections is presented. The data acquisition system is the group of components used to collect, compute and store the data gathered from the oxygen microsensor. The components of this system are the combined oxygen microsensor, a picoammeter, and an analog-to-digital converter. The motion control system is the group of components used to accurately position the microsensor at any location in a biofilm sample. The main components of this system are a motorized two-dimensional stage and a motorized micromanipulator. The software is a computer program developed in National Instruments' LabVIEW® and used to automatically synchronize the data acquisition system and the motion control system through a computer.

For the data acquisition system, as illustrated in Fig. 1, the oxygen microsensor was connected to a picoammeter (Unisense, Denmark, Model No. PA2000), the picoammeter was connected to an external analog-to-digital converter card (Pico Technology Ltd., Cambridgeshire, UK; Model ADC-101), and the analog-to-digital converter card was connected to a computer (Dell Model Inspiron 5000) using serial communication (LPT1 port).

In order to record data from the oxygen microsensor into the computer, the analog signal produced by the oxygen microsensor was converted to a digital signal. This signal process followed a series of steps. The oxygen microsensor converted a chemical signal, proportional to the dissolved oxygen concentration in the biofilm sample, into an electrical signal (current). That electrical signal was then transmitted to the picoammeter. Due to the small microsensor tip, the resulting electrical signal is very small (in the order of picoamperes) and needs to be amplified. The picoammeter amplifies the current signal and converts it to voltage. Then, the output voltage signal from the picoammeter was sent to the analog-to-digital converter to be converted to a digital signal. The analog-to-digital converter constantly receives an input voltage signal from the picoammeter and generates a digital output code proportional to the input voltage signal. Finally, the digital signal from the analog-to-digital converter was sent to the computer where it can be recorded by the computer program developed in LabWIEW®. The analog-to-digital converter was a 12-bit converter.

The motion control system consisted of three actuators that allowed the three-dimensional positioning of the microsensor. Two actuators were part of a two-dimensional stage for horizontal control (Phytron Inc., Waltham, MA, USA; Model