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Modelling Oxygen Transfer in Moving-Bed Biofilm Reactors Using Dimensional Analysis

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Introduction

Optimization of oxygen supply in wastewater treatment processes is needed in order to limit the energy expenditure of wastewater treatment plants (WWTP) and to guarantee the treatment efficiency. To this aim, models based on dimensional analysis [1,5] or computational fluid dynamics (CFD) [2] were developed to predict oxygen transfer efficiencies of classical fine bubble aeration systems. New treatment processes based on coarse bubble aeration system coupled with fluidized biomedias, which provide a large internal area for bacterial growth (Moving Bed Biofilm Reactors - MBBR and Integrated Fixed-Film Activated Sludge - IFAS), are now competitive and are often proposed for WWTP upgrading and new building. In these new systems, the oxygen transfer performance in the presence of biomedias is not well established [3] and models adjustment are needed for process optimization. The aim of this study is to provide models issued from dimensional analysis linking oxygenation performances in clean water to design and operating parameters for inverse fluidized bed reactors.

Material and methods

Models are developed using a database of 77 oxygen transfer performances on two rectangular semi-industrial scale pilots (the characteristics of the pilots are described in Table 1).

Table 1. Characteristics of the two semi-industrial scale pilots and operating conditions

Reactor	1	2	
H _{max} (m)	1.6	4.5	
V _{max} (m ³)	2.8	9.0	
Aeration system	FB / CB	FB / CB	
U _G (m s ⁻¹)	0 - 5.1x10 ⁻³	0 - 6.2x10 ⁻³	
Ref of biomedias	A	B	C
Filling ratio (%)	0 / 20 / 40 / 50	0 / 20 / 36	0 / 30 / 43 / 60

With: H_{max} = maximum liquid height / V_{max} = maximum volume of liquid / U_G = superficial air velocity / FB = fine bubble aeration / CB = coarse bubble aeration

The flexibility of these experimental devices enables to study the impact of most design and operating parameters such as reactor dimensions (surface, liquid height), characteristics of the aeration system (fine / coarse bubble diffusion, number and location of aerators), air flow rate and biomedias filling ratio (from 0 to 60% in volume). For each configuration, the oxygen transfer performances were determined in clean water according to the normalized non-steady state method [4].

Results

In this abstract, results are presented only for reactor 1. Results obtained on reactor 2 will be developed in the full version of the manuscript.

Exploiting the database allows to highlight the impact of major parameters on the oxygen transfer performances:

- Without biomedica, the oxygen transfer coefficient (k_{La20}) was mainly controlled by the superficial gas velocity and the installed aeration system (Figure 1), due to the bubble size and the resulting liquid flows. A linear correlation between k_{La20} and U_G is obtained, such as observed on full-scale plants [5].

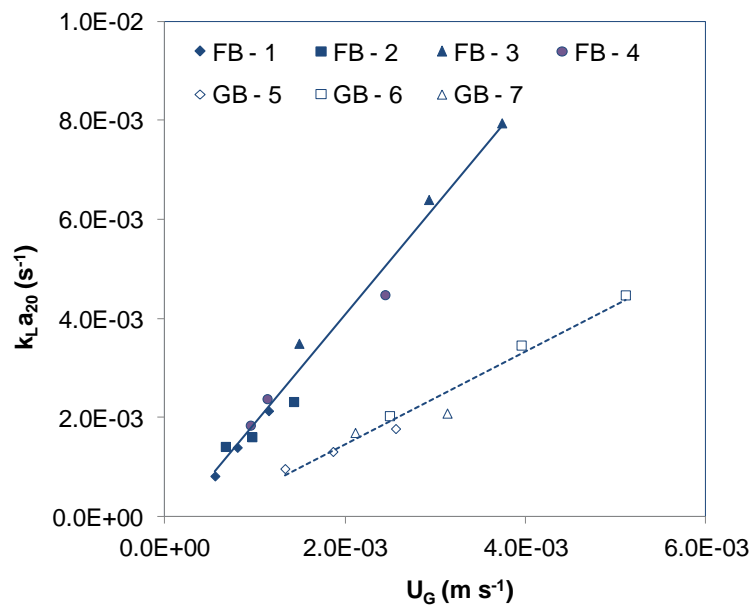


Figure 1. Oxygen transfer coefficient as a function of the superficial gas velocity for fine bubble (FB) and coarse bubble (GB) aeration for different configurations of reactor 1

- An increase in the biomedica filling ratio led to an increase in k_{La20} for coarse bubble aeration (Figure 2). This increase could be linked to a decrease in the mean bubble diameter and an increase in the gas/liquid contact time due to biomedica volume occupation. Preliminary results on reactor 2 showed that the oxygen transfer performance of fine bubble aeration systems were less impacted by the biomedica filling ratio in comparison than in coarse bubble aeration.

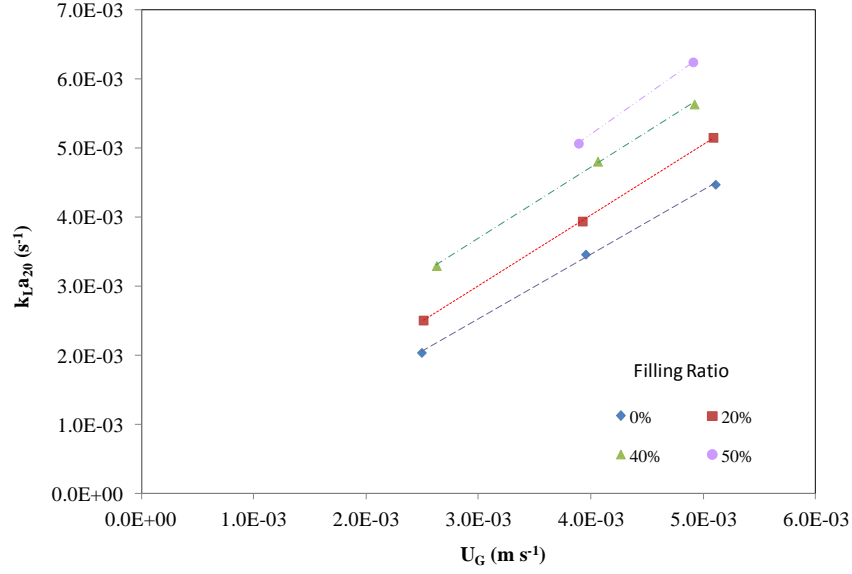


Figure 2. Oxygen transfer coefficient as a function of the superficial gas velocity and the biomedica fill ratio (Reactor 1 – Configuration 7 – V = 0.93 m³)

A model was developed on the basis of a dimensional analysis. The transfer number (N_T) is related to the Reynolds number ($Re = \frac{U_G \cdot h}{\nu}$), the ratio between the total perforated area of the diffusers (S_p) and the total area of the reactor (S) and the biomedica fill ratio (T_{RB}).

$$N_T = \frac{k_L a}{U_G} \left(\frac{\nu^2}{g} \right)^{1/3} = 1,19 \cdot 10^{-3} Re^{-0,13} \left(\frac{S_p}{S} \right)^{0,88} (1 - T_{RB})^{-0,51} \quad (\text{Eq. 1})$$

Where: $k_L a$ is the oxygen transfer coefficient (s⁻¹), U_G the superficial gas velocity (m.s⁻¹), ν the liquid cinematic viscosity (m².s⁻¹), h the diffuser submergence (m) and g the standard gravity (m.s⁻²)

This model is made independent of the aeration system characteristics (fine/coarse bubble) and enables to predict the transfer number with an average accuracy of 6%.

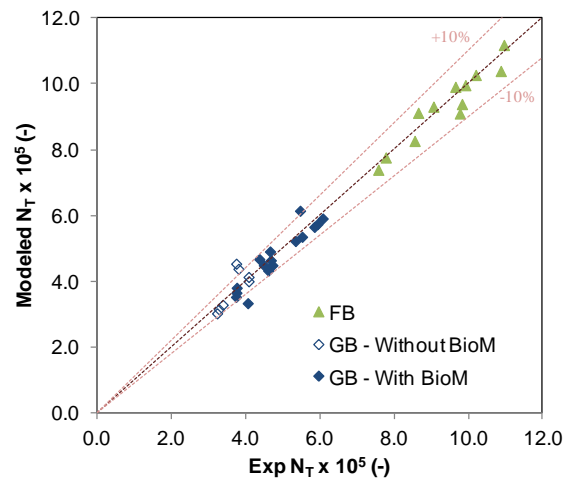


Figure 3. Modeled versus experimental transfer numbers for fine / coarse bubble aeration without/with biomedica

Conclusions

The development of models in order to optimize the oxygen transfer performances in inverse fluidized bed reactors commonly used in wastewater treatment is needed. To this aim, a database of 77 oxygen transfer measurements was built on two semi-industrial scale reactors. Exploiting this database for reactor 1 points out the impact of design and operating parameters on oxygen transfer performances. A model, based on dimensional analysis, is also build, allowing to predict the transfer number with a accuracy of 6%. Additional results on reactor 2 will be included in the full version of the manuscript.

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