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The effect of biofilm growth on hydrodynamic properties of bioreactors.

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1.Summary

The study of biofilm in porous media spans a wide range of application going from medical to environmental application. In this paper, we are interested in biofilter. These processes, widely used for pollution removal, are difficult to model. Indeed, biofilm growth is a complex process that involves fluid flow, mass transport and biotransformation : thus, biofilm growth in porous media raises many questions about hydrodynamic-biofilm interactions.

In order to have a better understanding of hydrodynamic-biofilm interaction, we have started a study that consists with a experimental work on a laboratory scale pilot. The originality of the experimental apparatus lies in the possibilty to measure many global parameters accounting for the biofilter hydrodynamic evolution with time. Pressure measurement gives access to the permability profile along the column. RTD measurement allows the derivation of the evolution of the mean biofilter porosity with time. Lastly, at the end of a typical experiment, the biofilter is emptied and the concentation of biological material is measured along several section of the biofilter. In order to have a macroscopic description of the biofilter behavior from the physics at the pore scale, this experimental study is supplemented with modelling using an upscaling technic. A keypoint in the model consists in the relation between the porous media permeabilty and the amount of biological matter in the biofilter. Many researchers, e.g Vandeviver (1995), Clement (1996), Thullner (2002) have presented models to relate the permeability with porosity in packed bed reactors. They have considered some hypothesis concerning the biofilm structure e.g homogenous and uniform growth of biofilm on the solid media. In this paper we present the methodology used to relate the permeability to the local porosity in the pilot The resulting relationship is then compared to existing model. Finally, this relationship is used in the model to check the ability of the model to describe the global behavior of the biofilter and explain some effects of the biofilm growth on the hydrodynamic properties of bioreactors.

Keywords: Bioreactor, Hydrodynamic, Biofilm Growth, Permeability, Porosity, Modelling

2. Extended abstract

A scheme of the experimental setup is presented in figure 1. It is mainly composed of a PVC column of 0.57 m long and 0.15 m in diameter (total volume of 0.014 m^3).The column is filled with expanded clay beads of 4 mm (Biolite®, Degrémont) (Prieto *et al.*, 2002). The flow of the two pumps is controlled in order to introduce constant oxygen and nutrient concentrations in the column. The nutrient solution contains both phenol and the growth

nutrients (diluted LB medium) necessary to the bacterial growth and the biofilm development.
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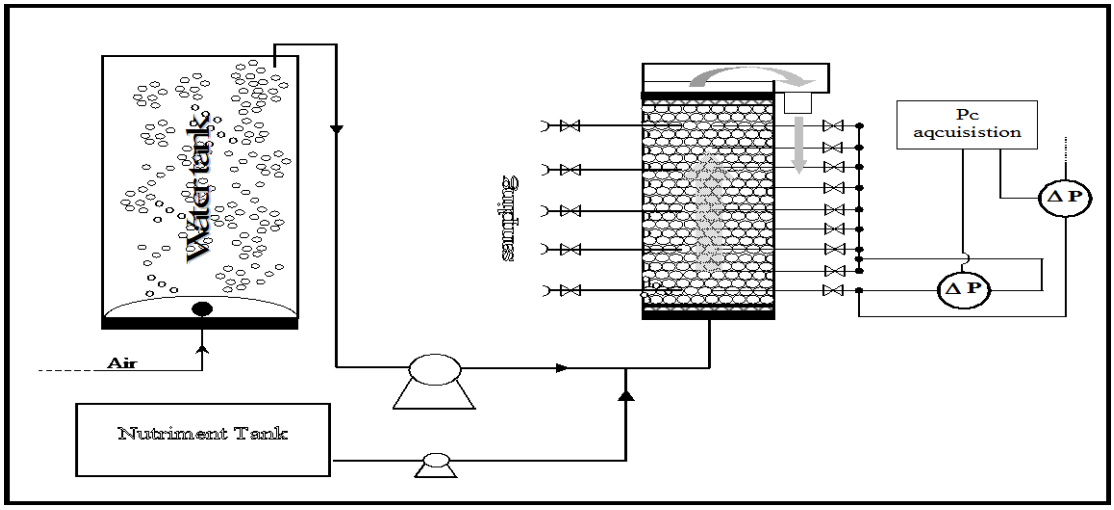

Figure 1: Experimental biofilter pilot plant (rajouter des numeros et les decrier dans la legende)
1/ bioreactor coumn, 2/ Sampling device (five sampling ports)

The permeability k_0 of the packed bed is measured at the beginning of the experiment via infiltration experiments conducted at various flows according to the Darcy's law (eq 1):

$$k_0 = \frac{Q_V \cdot \mu \cdot \Delta z_{19}}{\Delta P_{19} \cdot S} \qquad (1)$$

where: k_o is the medium permeability [m^2]
Q_V is the flow rate [$m^3 \cdot s^{-1}$]
μ is the dynamic viscosity [Pa·s]
S is the biofilter surface [m^2]
Δz_{19} is the distance between samplers 1 and 9 [m]
ΔP_{19} is the pressure drop between samplers 1 and 9 [Pa]

k_0 constitutes a reference value in the initial biofilter state.

The pressure profiles measured daily during the experiment are analysed following the same procedure to set the permeability profile $k_{i,i+1}(z,t)$, which informs on the biofilter clogging.

$$k_{i,i+1exp}(z,t) = \frac{Q_V \cdot \mu \cdot \Delta z_{i,i+1}}{S \cdot \Delta P_{i,i+1}(z,t)} \qquad (2)$$

where: $\Delta z_{i,i+1}$ distance between two consecutive samplers [m]
$\Delta P_{i,i+1}$ pressure drop between two consecutive samplers [Pa]

Figure 2 shows the evolution of total pressure drop in the biofilter during the biofilm development (Q_v = 5L h^{-1}, NaCl 0.25 g L^{-1}, yeast extract 0.25 g L^{-1} , phenol 0.2 g L^{-1}). The curves can be divided in three different zones: the first step, from the beginning to the third

day, shows a non significant increase of the pressure in the column. This observation indicates that the column pore volume is constant due to a lack of bacterial activity in the column. This phenomenon probably corresponds to the typical lag phase usually associated with bacterial growth.The second step occurs between the fourth day and the twelfth day. It shows a significant and linear increase of the pressure drop. During this eight days period, the pressure value reaches about 90mbar. This pressure rise is directly related to a permeability decrease in the granular matrix (cf eq 2). This characteristic behaviour is linked to bacterial growth since the biofilm develops around the granular clay balls and reduces the porosity of the packed bed.**T**he third phase of the curve presents a stabilisation of the pressure drop and of the clogged front inside the column. This state is due to the equilibrium between the different coupled processes such as the equilibrium between cell division and detachment that is mainly controlled by the local hydrodynamic conditions (shear stress…), substrate and oxygen availability (growth inhibition), and biofilm structure (thickness).

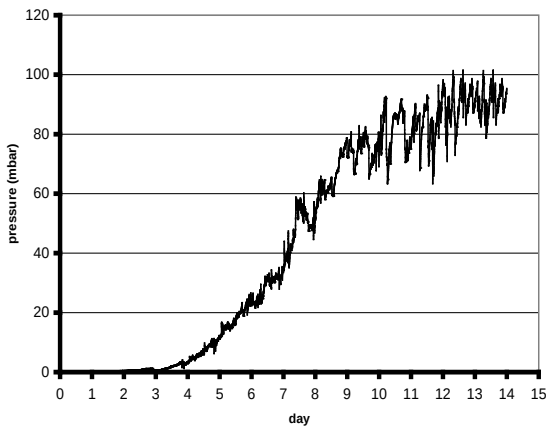

Figure 2: Total pressure drop inside the biofilter

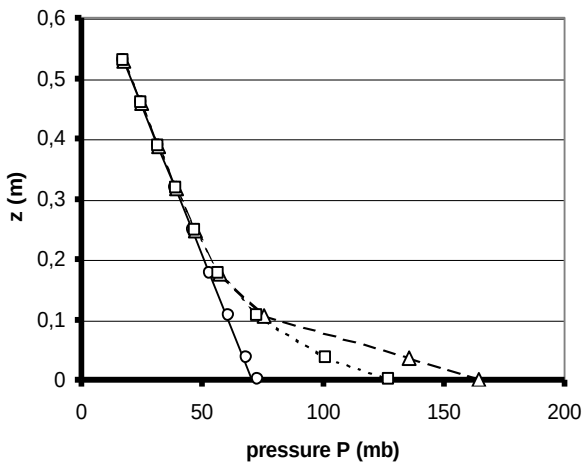

Figure 3: Theoretical (solid line, calculated with the Kozeny's Law) and measured pressure profiles after 4 days (○), 8 days (□); and 13 days (Δ) of biofilm development in the reactor

Figure 3 shows three pressure profiles measured after 4, 8 and 13 days of biofilm development. The profiles correspond to the experiment presented in Figure 2. is also showed in Figure 3, The theoretical pressure drop inside the granular medium is also presented in figure 3 (solid line) and was calculated with Kozeny's law:

$$\Delta P = 180 \cdot \frac{(1-\varepsilon)^2}{\varepsilon^3} \cdot \frac{\mu \cdot u}{d_p^{\,2}} \qquad (3)$$

where ε is the porosity, ρ is the specific mass [kg m^{-3}], μ is the dynamic viscosity of the fluid [Pa.s], d_p is the granular diameter [m], u is the superficial fluid flow rate through the medium [$m.s^{-1}$]

The bacterial growth induces a porosity decrease that causes an increase of the pressure drop in the lower layers. This pressure drop evolves from low values at the 4th day to a maximum reached on the 13th day. This maximal value, (150 mb) is observed within the first bottom layer of the biofilter.