Biofilm growth at high COD and particle concentration levels: application to the case of micro-irrigation emitters used for wastewater reuse

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BIOFILM GROWTH AT HIGH COD AND PARTICLE CONCENTRATION LEVELS: APPLICATION TO THE CASE OF MICRO-IRRIGATION EMITTERS USED FOR WASTEWATER REUSE

DEVELOPPEMENT DU BIOFILM A FORTE CONCENTRATION EN DCO ET EN PARTICULES MINERALES : APPLICATION AU CAS DES GOUTTEURS DE MICRO-IRRIGATION POUR LA REUTILISATION DES EAUX USEES

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ABSTRACT

Wastewater reuse can properly supply irrigation demand by adopting suitable techniques and practices. Micro-irrigation optimizes water application and minimizes health hazards and crop contamination risks. Nevertheless, clogging is a common problem when using drip irrigation. In this study, we focus on emitters clogging due to biological and physical deposits. Experiments were carried out to investigate the interaction between biofilm growth and mineral particle deposits on 3 types of online emitters using a 200 mg.L^{-1} COD synthetic effluent with and without mineral particles (size range : 0 to 80 µm). Emitter performance was monitored using flow rate measurement. Moreover the deposits of mineral particles and biofilms were analyzed optically, collected and dried at 105°C for 24 hours. Biofilm and mineral deposit induces flow rate decrease from the 30th day of the experiment. However, without mineral particles, emitter flow rate decrease was more significant. Thus, mineral particles seem to have an abrasive effect on biofilm depending on flow structure.

RÉSUMÉ

La réutilisation des eaux usées traitées (REUSE) peut subvenir à la demande en eau d'irrigation en utilisant des techniques économes en eau. La micro-irrigation permet d'optimiser les apports en eau et de réduire les risques sanitaires liés à la REUSE. Cependant, le colmatage des systèmes d'irrigation est un inconvénient majeur. Dans cette étude, nous nous intéressons au colmatage d'origine physique et biologique. Des expérimentations ont été réalisées pour étudier l'interaction entre le développement de biofilm et le dépôt de particules minérales dans 3 types de goutteurs en utilisant un effluent synthétique à 200 mg.L^{-1} en DCO avec ou sans particules minérales (taille variant entre 0 et 80 µm). Le débit des goutteurs a été suivi au cours de l'expérimentation. De plus, les dépôts ont été analysés optiquement puis prélevés et séchés à 105°C pendant 24h. Le débit diminue à partir du 30ème jour d'expérimentation suite au développement de biofilm et au dépôt de particules. Cependant, la diminution du débit est plus importante sans l'ajout de particules minérales qui semblent avoir un effet abrasif sur le biofilm en fonction des conditions d'écoulement.

Keywords: Biofilm, drip irrigation, mineral, wastewater reuse

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1. Material and methods

1.1 Experimental set-up

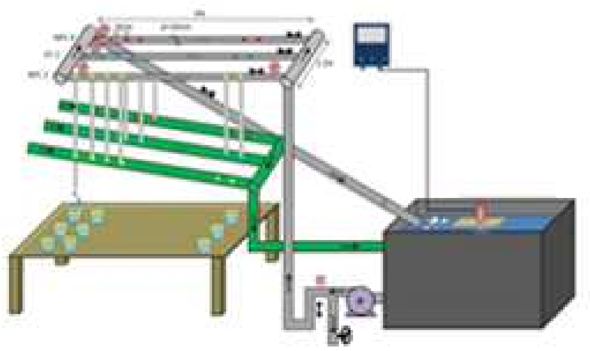

Figure 1. Experimental setup

The experimental setup (Figure 1) consists of 3 lines of 16 mm diameter polyethylene pipes of 4 m length. 20 online drippers are plugged on each line (NPC2, PC and NPC4). The emitters used are showed in Figure 2:

- NPC2 (non-pressure compensating emitters delivering 2 $L.h^{-1}$ at 100 KPa). Water circulates through a labyrinth which regulates flow rate.
- PC (pressure compensating emitters): Flow rate remains constant in a pressure range between 100 and 300 KPa. These emitters contain an elastomeric membrane.
- NPC4: characteristics are the same as for NPC2. The nominal flow rate at 100 KPa is 4 $L.h^{-1}$.

This system operates 8 hours/day. Pressure is maintained at 1 bar to obtain 2 $L.h^{-1}$ for PC and NPC2 and 4 $L.h^{-1}$ for NPC4. Water is collected at emitter outlet and returned to an 800 L tank containing a 200 $mg.L^{-1}$ COD synthetic effluent. This concentration is about 4 times higher than that defined by the French standard (60 mg L^{-1}; class A effluent) for wastewater reuse (French ministry of social affairs and health, 2014) in order to obtain a measurable amount of biofilm during the experiment. The effluent composition is detailed in table 1. The solution is renewed every week to supply enough nutrient for biofilm development.

Two experiments were carried out. The first one is conducted using the composition described in table 1. For the second experiment, the effluent is used without mineral particles to deduce their effect on biofilm growth. The particles are extracted from soil samples, dispersed using Sodium Hexametha phosphate and treated with oxygen peroxide to remove organic matter then sorted using ISO 17892 sedimentation methods.

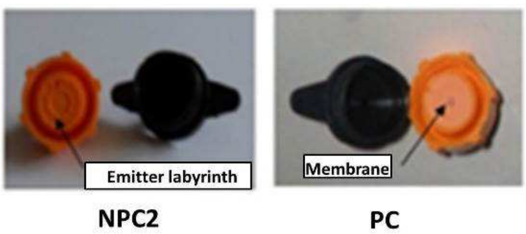

Figure 2. Emitters

Component	Concentration
Viandox	0,65 g/L
Sucrose	0,035 g/L
Phosphoric acid	0,3 mL
Ammonium chloride	0,028 g/L
Mineral particles (0-80µm)	0,2 g/L

Table 1. Composition of the synthetic effluent

1.2 Experimental measurements

1.2.1 Flow rate

Flow rate measurements are carried out by collecting the effluent at emitter outlet during ten minutes. The collected volume is then weighed using a balance (accuracy ± 1 g).

1.2.2 Deposit analysis

Some emitters have been removed from the experimental setup and replaced by new ones since the 4th week of the experiment. Drippers are opened and the deposits were observed using an Olympus BX43 microscope using a 10X magnification. Then, emitter labyrinths and membranes are placed in a tube with 1 mL of water and centrifuged at 6000 $rev.min^{-1}$ during 10 minutes in order to detach the deposits. The volume collected after centrifugation is dried at 105 ° C for 24 hours and weighed to obtain the dried mass.

1.2.3 Physicochemical measurements

Temperature, pH and conductivity were monitored daily during the first and second experiment (with and without mineral particles). Physicochemical characteristics are summarized in Table 2.

Experiment	pH	Temperature (°C)	Conductivity (µS/cm)
With mineral particles	7,85 ± 0,48	18 ± 3	907 ± 65
Without mineral particles	8,68 ± 0,67	30 ± 4	1146 ± 89

Table 2 Physicochemical measurements

2. Results and discussion

2.1 Emitter performance with mineral particles

Figure 3 shows flow rate variations during the experiment performed with mineral particles using the emitters described in section 1.1. Flow rate variations are significant during the first 30 days of the experiment and tend to exceed the nominal flow rate (around 5% for NPC2 and PC and 10% for NPC4). A decrease on flow rate is observed from the 30th day. At the end of the experiment flow rate has decreased by 17% for NPC2 emitters, 23% for PC and 4% for NPC4. PC and NPC2 emitters tend to clog faster than NPC4.

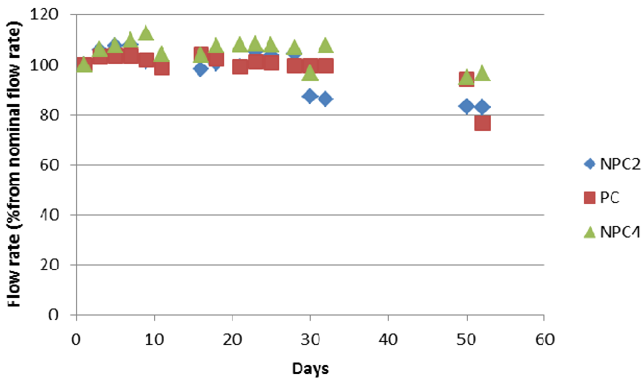

Figure 3. Flow rate variation with mineral particles

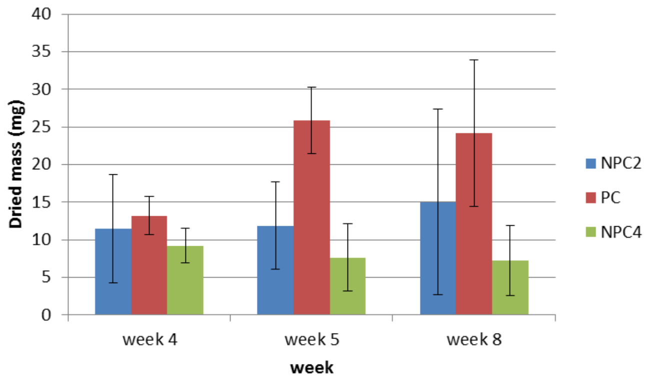

Figure 4. Dried mass

Figure 4 shows the variation of emitter dried deposit masses. Error bars correspond to the standard deviation calculated for four samples removed at the same date. At the 4th week, dried masses were of the same order of magnitude for the three types of emitters. However, from the 5th week, the deposit increases especially for PC emitters. Deposit dried mass has increased by 3,6 mg for NPC2 and 11 mg for PC, while it remains constant for NPC4. Significant variations are observed for standard deviation. For example, the coefficient of variation[5] (cv) calculated for NPC2 vary from 50% at the 5th to 80% at the 8th week which reveals the deposit heterogeneity between different emitters at the same date.

For non-pressure compensating drippers (NPC2 and NPC4), flow rate increases observed in figure 3 at the beginning of the experiment may be related to the presence of particles. Bounoua et *al*. (2015) explained this phenomenon by two assumptions: (i) particles interact with the smallest flow structure scales and tend to streamline it and (ii) particles deposit in emitter labyrinth tend to smooth wall roughness, which change the characteristics of the flow. However, the experiments performed by Bounoua et *al.* (2015) were conducted with a mixture of clay and limestone particles (average diameter = 5 µm) which is below particle diameters currently tested. The second hypothesis is thus the most likely.

Dried mass trapped in the drippers is lower for NPC4 than for NPC2. This variation is related to nominal flow variations. El Khatib (2011) described the detachment of bacterial cells with shear forces induced by significant water velocity exerted on biofilm structure. Then, biofilm tend to develop in flow path zones with the lower shear stress (Gamri et *al*., 2014) namely the central circle (Figure 5).

NPC4 and NPC2 emitters are less sensitive to clogging than pressure compensating drippers (PC). Dried mass is higher in PC emitters compared to NPC (Figure 4). At the end of the experiment, the deposit removed from PC emitters is 1,5 time higher than NPC2. However, PC flow rate decrease is close to NPC2. This phenomenon can be explained by the fact that biofilm and particle deposits on membranes (Figure 6) has a smaller effect on PC emitter functioning. Also, NPC emitters can be more sensitive to clogging because of labyrinth width (about 1 mm).

[5] is a standardized measure of dispersion of a probability distribution and is defined as the ratio of the standard deviation to the mean.

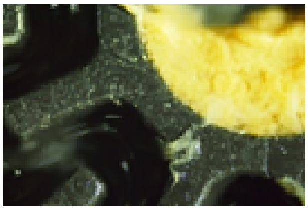

Figure 5. Deposit on NPC emitter

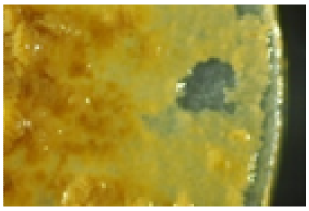

Figure 6. Deposit on PC emitter

2.2 Interaction between biofilm and mineral particles

Figures 7 and 8 show flow rates and dried masses measured for NPC2, PC and NPC4 emitters at the end of the experiment (8 weeks) with and without adding mineral particle in the effluent used. Dried masses measured in the experiment with mineral particles (Figure 7) are significantly higher than those measured without particles (Figure 8). For NPC2 emitters, the dried mass measured with particles is around 15 ± 12 mg, and around 2,4 ± 0,2 without particle. In the first case the weight of biofilm is combined to particles which explain mass increase. Nevertheless, flow rate is less affected when mineral particles are used. For NPC2, flow rate decreases by 50% without mineral particles and by 18% with particles. Mineral particles have a little effect on emitter clogging compared to biofilm growth.

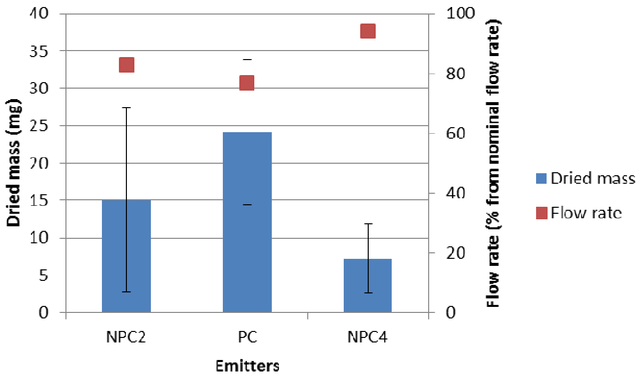

Figure 7 Flow rate and dried mass measured for NPC2, PC and NPC4 emitters and the end of the experiment with particles

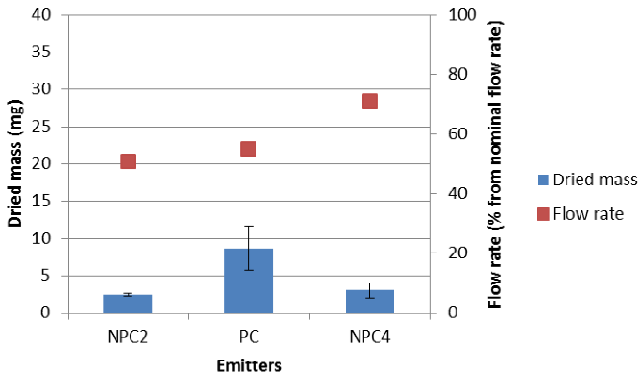

Figure 8 Flow rate and dried mass measured for NPC2, PC and NPC4 emitters and the end of the experiment without particles

3. Conclusion and perspectives

To better understand the phenomenon involved on the interaction between biofilm and mineral particles, we will develop the use of milli-channels with simplified geometry to investigate the mechanics of interactions between fluid, particles and walls.

In the long term, our objective is to focus on the interaction between the biofilm and mineral particles in situ using treated wastewater.

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