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Presence of biofilms on ultrafiltration membrane surfaces increases the quality of permeate produced during ultra-low pressure gravity-driven membrane filtration

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ABSTRACT

This study evaluates the effect of the presence of biofilms on membrane surfaces on the quality of permeate produced during Gravity-driven membrane ultrafiltration. GDM ultrafiltration is applied to the decentralized production of drinking water. A second objective was to evaluate to what extent permeate quality is enhanced by pre-treating feed-water (using a packed bed biofilm reactor or a slow sand filter). The influence of the ageing of the biofilm on the permeate quality was evaluated and compared to the effect of virgin membranes. Permeate quality was evaluated in terms of Assimilable Organic Carbon (AOC) content and dissolved organic carbon fractions (e.g. biopolymers). Our results indicate that virgin ultrafiltration membrane remove a small fraction of the AOC and biopolymers (rejection <10%). The presence of a young and thin biofilm on the surface of the ultrafiltration membranes increases the permeate quality due to the degradation of AOC (>80%). However, over long-term the hydrolysis of the organic matter that accumulated on membrane surfaces increases the AOC content of the permeate, thus deteriorating the permeate quality. Pre-treatment of the feed-water help to control the biofilm accumulation and thus to limit the deterioration of the permeate quality. Permeate flux stabilised at average values of 7.5–8.9 L m^{-2} h^{-1}. But the presence of pre-treatment helped to increase permeate flux (+12 and 19%, with the packed bed biofilm reactor and with the slow sand filter, respectively). Overall our study demonstrates that tolerating the presence of biofilm on membrane surface has a beneficial effect on the quality of permeate even if its quantity is decreased.

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1. Introduction

Ultra-low pressure Gravity-driven membrane (GDM) filtration is a relevant technology that can be used for the decentralized production of drinking water in developing and transient countries (Peter-Varbanets et al., 2009). These systems are associated with no/low maintenance needs and are operated "off-the-grid", i.e., without connections to any energy supply. Biofilm formation on membrane surfaces is tolerated during GDM filtration. Ultra-low pressure GDM systems are indeed operated in a dead-end mode, using gravity as the main driving force without control of the biofouling. Lab-scale experiments and field-testing proved that the formation of highly permeable biofilms is associated with long-term (several month) flux stabilization (between 3 and 15 L m^{-2} h^{-1}) (Derlon et al., 2012; Peter-Varbanets et al., 2009). However none of the previous studies on GDM filtration addressed the effect of the biofilm on the permeate quality. The quality of a water source is defined by its microbial stability, i.e., the absence of uncontrolled bacterial growth (Meylan et al., 2007). The amount of assimilable organic carbon (AOC) is conventionally measured to diagnose the risk of water quality deterioration due to microbial regrowth (Van Der Kooij et al., 1982). Microbial stability is achieved through significant reduction of growth-limiting compounds.

During GDM filtration the biofilm formation results from an interplay between different processes such as retention of organic particulate matter, solute degradation, predation, etc. In conventional membrane system such as nano-filtration, the systems are operated at high pressure and with control of the biofilm formation and no or low solute degradation by the biofilm is reported (Hijnen et al., 2009). In such a system, the formation of the biofilm is strongly limited by diverse intensive control strategies (backwashing, chemical cleaning, etc). This extensive control of the biofilm formation on membrane surface in turn limits its influence on the permeate quality, conventionally evaluated through the measurement of the Assimilable Organic Carbon (AOC) concentration. However in GDM systems the accumulated amount of biofilm on membrane surfaces is higher due to the absence of control strategies. It is thus unclear how the presence of the biofilm on the membrane surface influences the degradation of organic compounds and in turn the quality of the permeate produced during GDM ultrafiltration. We hypothesized that the degradation of solutes by the biofilm is enhanced and increases the permeate quality.

Pre-treatment of the surface water before the GDM unit represents a relevant approach to increase the permeate quality and flux. Biofiltration processes have been used for decades to remove organic compounds from surface waters (Graham, 1999). These processes are efficient to remove both particulate and soluble organic compounds. Removal efficiencies of 22–32% and 4–50% were reported for Particulate Organic Carbon (POC) (Halle et al., 2009) and for Dissolved Organic Carbon (DOC) (Graham, 1999), respectively. If the DOC is mainly composed of humic substances, lower removal efficiencies are reported (5–19%), which probably indicates that humic substances are slowly biodegradable (Graham, 1999). Humic substances, however, have a minor influence on the biofouling of membrane systems (Huang et al., 2008; Jarusutthirak et al., 2002). On the other hand, biopolymers have a major impact on biofouling (Filloux et al., 2012). Biopolymers are produced during microbial growth, biomass decay, and also hydrolysis of organic substrates (Ni et al., 2011). The degradability of biopolymers is higher than the one of humic substances. Thus, higher removal efficiencies of 40–60% are reported for biopolymers than for humic substances in slow sand filters (Halle et al., 2009). GDM filtration is strongly influenced by the presence of biopolymers (Peter-Varbanets et al., 2011). An increasing biopolymer concentration in the feed water induces a decreasing permeate flux even if flux stabilization is still observed (Peter-Varbanets et al., 2011). If biofiltration helps to remove organic compounds present in the feed water and especially the biopolymeric substances, it can be hypothesized that biofiltration performed before GDM units could help to increase the filtration performances in terms of permeate quality and quantity.

This study thus aimed at (i) understanding how the presence of biofilms on membrane surfaces influences the quality of permeate produced during GDM filtration and (ii) evaluating to what extent the quantity and quality of permeate can be increased by pre-treatment of the feed water. Three different systems were operated in parallel with/without pre-treatment of the feed water. Two pre-treatment strategies were tested with regard to their efficiency to removal particulate and soluble organic compounds: Packed Bed Biofilm Reactor (PBBR) and Slow Sand filtration (SSF). The effect over short-term (several weeks) of the biofilm formation was distinguished from its effect over long term (several months). Assimilable organic carbon (AOC) is the conventional parameter used to diagnose the risk of water quality deterioration due to microbial regrowth (Van Der Kooij et al., 1982). Permeate quality was thus evaluated through the measurement of the assimilable organic carbon (AOC) content. The soluble and particulate organic compounds (e.g. POC, AOC, biopolymers, etc.) were monitored using TOC analyser and Liquid Chromatography coupled to an Organic Carbon Detector.

2. Materials and methods

2.1. *Experimental approach and set-ups*

Three different experiments were performed to evaluate how the formation of biofilms on membrane surfaces influences the quality of permeate produced during GDM filtration (Table 1). The influence of the formation of young biofilms (biofilm age <45 days) fed with a sodium acetate-based feed water or with natural river water was investigated in experiment 1 and 2, respectively. In experiment 3 the effect of mature biofilms (biofilm age up to 4 month) was evaluated using natural river water. In these three experiments a "GDM control system" was operated without pre-treatment. In experiment 3 the performances of the GDM control system was compared to GDM systems equipped with pre-treatments, i.e., a Packed Bed Biofilm Reactor (PBBR) and a Slow Sand Filter (SSF), respectively named "PBBR + GDM" and "SSF + GDM" systems. We expected that the PBBR and SSF remove a significant amount