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Analysis of fouling development under dynamic membrane filtration operation

Mubashir Saleem [a], Luca Alibardi [b,*], Raffaello Cossu [c], Maria Cristina Lavagnolo [c], Alessandro Spagni [d]

[a] Department of Civil, Environmental and Architectural Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy
[b] Cranfield Water Science Institute, Cranfield University, Bedford MK43 0AL, UK
[c] Department of Industrial Engineering, University of Padova, via Marzolo 9, 35131 Padova, Italy
[d] Laboratory of Technologies for Waste, Wastewater and Raw Materials Management, Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), via M.M. Sole 4, 40129 Bologna, Italy

HIGHLIGHTS

- Cake filtration model effectively describes dynamic membrane formation and fluxes.
- Suspended solids concentration significantly affects dynamic membrane performance.
- Mesh pore size does not significantly affect dynamic membrane development and flux.

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ABSTRACT

This research is a contribution towards evaluating the appropriate fouling mechanism responsible for the flux decline under dynamic membrane (DM) filtration and its formation mechanism by using gravity-driven filtration in a specifically designed experimental setup. Series of extended short term filtration experiments were performed at varying operating conditions of mixed liquor suspended solids (MLSS) concentrations, trans-membrane pressures (TMP) and mesh pore sizes. Blocking models were applied to identify the fouling mechanisms occurring in DM development. The results demonstrated that cake filtration model can adequately describe fouling mechanisms during DM filtration. According to the analysis of variance, DM development, as described by flux (*J*) trends during filtration, was significantly affected only by MLSS concentration while effluent turbidity was significantly affected by MLSS concentration and TMP. On the contrary, *J* and effluent turbidity trends during filtration were not significantly influenced by mesh pore size, at least in the range used in this study (10–200 μm).

1. Introduction

The use of membranes in wastewater treatment is finding growing application due to their complete solid retention, flexibility in operation and small footprints. However, high capital and operating cost and inevitable fouling phenomenon hinders their extensive application [1]. In this regard, dynamic membranes (DMs) represent an attractive alternative to the use of conventional microfiltration and ultrafiltration (MF/UF) membranes by positively employing the fouling cake as a mean for solid liquid separation [2–4]. DM is a fouling surface that is formed by the deposition of suspended solids, colloids or microbial cell particles over an underlying support material (meshes, filter cloth etc.) [4–8]. Meshes of different porosity ranging from 10 to 500 μm have been reported in literature as a suitable support material for developing DMs [7–11]. The filtration mechanism of DMs is quite different to conventional MF/UF membranes in a way that, after the formation of DM layer, the filtration resistance is exclusively caused by the cake layer [7]. However, an excessive growth of a thick and dense fouling layer hinders a long term filtration operation due to excessive loss of permeability [2,12]. Therefore, the identification of operating parameters (e.g. nature and characteristics of the constituting particles, underlying support, suspended solids concentration, mesh pore sizes and hydrodynamic conditions) affecting the DM development remains crucial for practical large scale applications [3,12–16] but the management of these parameters to ensure performance reproducibility and control of transmembrane pressure (TMP) still represents a challenging task for DM implementation.

* Corresponding author.
E-mail address: l.alibardi@cranfield.ac.uk (L. Alibardi).

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Mathematical modelling is a useful tool that has been widely applied to analyse fouling in conventional membranes. Four models have been proposed to assess the fouling evolution over time in the form of complete blocking, intermediate blocking, standard blocking and cake filtration models. Complete pore blocking mechanism takes the assumption that the particles reaching the membrane surface block membrane pores without superposing other particles whereas, in intermediate blocking mechanism particles have an equal probability to deposit on other particles that ultimately cause pore blocking. Standard blocking, assumes that the particles deposit on the pore inner surface that gradually leads to pore constriction and ultimately to pore blocking. Cake formation mechanism is based on the assumption that particles reaching the membrane surface are larger than the membrane pore size and hence, they do not block them, rather form a layer on the membrane surface.

Hermia [17] derived mathematical equations describing flux evolution over time under constant pressure filtration for these four blocking mechanisms (Table 1).

Some authors have stated that the fouling process could also be governed by a combination of these mechanisms occurring simultaneously or at different stages during a filtrations operation depending upon the characteristics of the membrane, feed and operating parameters like filtration flux (J) and TMP [18–22].

These models [17] have found several applications in studying the fouling mechanisms in conventional membrane filtration, and although fouling processes play a decisive role in DM development, very few authors have tried to specifically understand how these phenomena occur in DMs by model-based analyses [6,7]. In fact, to the best knowledge of the authors, no studies have been performed yet to specifically evaluate the fouling development in DM by using mathematical modelling and, in particular, if the fouling models developed for membrane filtration can also be applied for DMs. Furthermore, the use of mathematical modelling to elucidate the formation mechanism of DMs in conjunction with the effect of changes in operating conditions (TMP and suspended solids concentration) on model response and its interpretation is still limited.

To date, studies have mainly been focused on evaluating the effect of different operating conditions and process variables on the development and performance of DM [2,3,8–15,23,24], while very few studies have discussed the mechanism governing the formation of DMs [5–7]. To the best knowledge of the authors, there is a lack of information about the effect of changing parameters on the mechanisms involved in DM formation.

The aim of this study is to understand the main mechanisms governing DM formation and to evaluate the possible effects of variation of operating parameters on DM development and performance. Filtration tests were carried out with a set of diverse operating conditions in a specifically designed experimental set-up. The results obtained from these experiments were analysed by blocking models proposed by Hermia [17] to predict the most likely fouling mechanism occurring in DM filtration.

2. Materials and methods

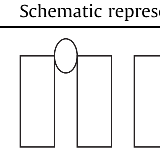
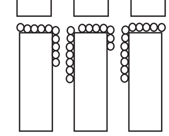
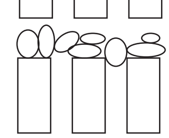
2.1. Experimental setup

The study was conducted at laboratory-scale in a specifically designed apparatus (Fig. 1). The experimental setup consisted of a 10 L stirring tank connected to an external filtration vessel by means of a peristaltic pump (Watson-Marlow 604U, Italy). The contents of the stirring tank were kept completely mixed by using an overhead stirrer (LS F201A0151, VELP Scientifica, Italy) operating at 200 rpm. The filtration vessel was made from a 1 mm thick Plexiglas tube having an internal diameter of 42 mm and a length of 180 mm. The filtration module contains a nylon mesh wound over a cylindrical support made of plastic with an external diameter of 35 mm and a length of 68 mm. The openings (6 mm × 5 mm) of the supporting cylinder were uniformly distributed with an effective filtration area of 58.3 cm^2. The cylindrical support was placed concentric to the filtration vessel in order to maintain a uniform hydraulic regime around the mesh surface. The stirring tank was filled with anaerobic sludge with total solids (TS) concentration of 12.3 g L^{-1} and volatile solids (VS) concentration of 7.13 g L^{-1} respectively. The sludge was collected from a full-scale mesophilic sludge digester treating the excess sludge of the municipal wastewater treatment plant of Padova, Italy. The required MLSS concentration was then attained by concentrating the sludge through settling or diluting by adding the supernatant of the same sludge.

2.2. Filtration experiments

A series of short term filtration experiments were performed at different operating conditions of mesh pore sizes, mixed liquor

Table 1
Summary of characteristic equations for constant pressure filtration laws proposed by Hermia [17].

Fouling mechanism	Model	Blocking constant	Physical description	Schematic representation
Complete blocking	$J = J_o e^{-K_b t}$	K_b	Pore blocking	
Standard blocking	$J = \frac{J_o}{\left(1+\frac{K_s J_o^{\frac{1}{2}} t}{2}\right)^2}$	K_s	Pore constriction	
Intermediate blocking	$J = \frac{J_o}{(1+K_i J_o t)}$	K_i	Pore blocking + surface deposition	
Cake filtration	$J = \frac{J_o}{(1+2K_c J_o^2 t)^{\frac{1}{2}}}$	K_c	Surface deposition