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Particle-sparged anaerobic membrane bioreactor with fluidized polyethylene terephthalate beads for domestic wastewater treatment: Modelling approach and fouling control

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ABSTRACT

The study presents a mathematical model developed to better understand and control membrane fouling in a single-staged, anaerobic fluidized bed membrane bioreactor (AFMBR) using polyethylene terephthalate (PET) beads as scouring media. The model was based on combining the anaerobic biological model AM2b and a fouling model applied in membrane filtration. The presented model was validated using experimental data obtained by a laboratory scaled AFMBR reactor run during 250 d under various operational conditions. The combined AM2b and fouling model was able to simulate volatile suspended solids, soluble COD concentration, soluble microbial products concentrations and the methane production rate at steady-state condition with R^2 of 95% as well as the trans-membrane pressure with R^2 of 99%. The model was able to predict dominant fouling mechanism by assessing fouling resistances caused by cake formation and pore blocking separately.

1. Introduction

Anaerobic membrane bioreactor (AnMBR) has been widely considered for wastewater treatment since (i) the biological treatment under anaerobic conditions is able to remove the majority of organic pollutant while producing biogas in the form of methane, and (ii) the membrane separation by microfiltration or ultrafiltration permits a complete separation of the solid phase and the liquid phase to obtain a highly purified water (Shin and Bae, 2018). Moreover, the membrane in AnMBRs allows for the hydraulic retention time (HRT) and solid retention time (SRT). Consequently, HRT can be decreased for higher water productivity and SRT can be increased for more efficient biological treatment (Jeong et al., 2017). Nevertheless, membrane fouling is still the main issue hindering AnMBR expansion for domestic wastewater treatment (Zhang et al., 2013). The reactor bulk has a complex composition including different foulant materials such as suspended solids, colloidal materials and humic like substances. All of them can be deposited on the membrane surface and/or inside its pores, and thus reducing membrane performances eventually (Gao et al., 2011). Numerous ways using physical and chemical cleaning procedures have been considered to alleviate membrane fouling. Nevertheless, conventional ways to control membrane fouling with AnMBR such as gas sparging often require high energy costs.

Recently, there is an upsurge of interest in fluidizing solid media along membrane surface by bulk recirculation through AnMBR reactor. The introduction of granular media into AnMBR has gained significant attentions with the development of the anaerobic fluidized bed membrane bioreactor (AFMBR) (Kim et al., 2011) and flourished during last several years (Düppenbecker et al., 2017; Aslam et al., 2018). Porous media such as granular activated carbon (GAC) have been widely used as fluidized media in the AFMBR because it can provide high surface area for biofilm formation. In addition, membrane surface can be cleaned effectively by scouring effect driven by fluidizing GAC particles with about 2–3 mm in size (Aslam et al., 2014, 2017a,b,c). GAC breakage can usually be encountered during a long-term AFMBR operation and this results in formation of small GAC particles with size smaller than 0.1 mm. Smaller GAC can contribute to membrane fouling rather than alleviating it because they can be deposited on membrane surface easily (Ma et al., 2012; Wu et al., 2016).

Modelling tool could be useful to better understand and control membrane fouling in AFMBR. Many models have been developed to simulate TMP change with time to quantify fouling intensity at constant flux operation (Charfi et al., 2018). Based upon the resistance in series model and Darcy's law or based on the classic blocking models considered separately or combined, those models are purely physical. In other works, the developed models describe the abiotic parameters only

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Nomenclature

A	membrane open area (m^{2})
A_0	initial membrane open area (m^{2})
A_b	membrane blocked area (m^{2})
A_f	free membrane area (m^{2})
b	S_2 yield from SMP (–)
b_1	SMP yield from S_1 (–)
b_2	SMP degradation by X_1 (–)
b_3	SMP yield from S_2 (–)
k_1^*	yield for S_1 degradation (–)
k_2^*	yield for S_2 production (–)
k_3^*	yield for S_2 consumption (–)
k_4^*	yield for CH_4 production (L/g_{COD})
K1	half saturation constant (kg.m^{-3})
K2	half saturation constant (kg.m^{-3})
Ki	inhibition constant (kg.m^{-3})
K	half saturation constant (kg.m^{-3})
k_{d1}	acidogens decay rate (d^{-1})
k_{d2}	methanogens decay rate (d^{-1})
m_c	specific cake mass (kg.m^{-2})
$m_{c,lim}$	specific cake mass reached at steady state (kg.m^{-2})
m_{att}	specific cake mass attached to the membrane (kg.m^{-2})
m_{det}	specific cake mass detached from the membrane (kg.m^{-2})
n	cake compressibility
Q_w	withdraw flow rate (m^{3}.s^{-1})
Q_{in}	feed flow rate (m^{3}.s^{-1})
Q_{out}	permeate flow rate (m^{3}.s^{-1})
Rc	cake resistance (m^{-1})
Rp	pore blocking resistance (m^{-1})
R_0	intrinsic membrane resistance (m^{-1})
S_1	COD concentration (kgCOD.m^{-3})
S_2	VFA concentration (kgequivalent acetate.m^{-3})
S	SMP concentration (kg.m^{-3})
TMP	*trans*-membrane pressure (Pa)
TMPc	*trans*-membrane pressure due to the cake formation (Pa)
TMPp	*trans*-membrane pressure due to pore blocking (Pa)
V_R	reactor volume (m^{3})
X_1	acidogens concentration (kg.m^{-3})
X_2	methanogens concentration (kg.m^{-3})
X_{VSS}	total suspended solid (kg.m^{-3})
α	specific cake resistance (m.kg^{-1})
$\alpha0$	initial specific cake resistance (m.kg^{-1})
β	cake mitigation parameter (m^{2}.kg^{-1})
γ	pore blocking mitigation parameter
δ	pore blocking parameter (m^{2}.kg^{-1})
λ	factor expressing the effect of cake formation on pore blocking
μ_p	permeate viscosity (Pa.s)
μ_1	growth rate of acidogens by consuming organic matter (d^{-1})
μ_2	growth rate of methanogens by consuming VFA (d^{-1})
μ_{smp}	growth rate of acidogens by consuming SMP (d^{-1})
μ_{max1}	maximum growth rate of acidogens by consuming COD (d^{-1})
μ_{max2}	maximum growth rate of methanogens by consuming VFA (d^{-1})
μ_{max3}	maximum growth rate of acidogens by consuming SMP (d^{-1})
σ	SMP fraction rejected by the membrane (–)
φ_{CH4}	Methane flow rate (mol$_{CH4}$.L^{-1}.day^{-1})

and neglect the biological dynamics (Paul and Jones, 2015). Even if many efforts have been made to combine biological ASM models and filtration models for aerobic MBR systems (Lee et al., 2002; Di Bella et al., 2008; Zuthi et al., 2012) few models have combined anaerobic digestion models with fouling models for anaerobic membrane bioreactors (Charfi et al., 2017a).

In this paper a mathematical model was developed by combining the anaerobic biological model AM2b (Benyahia et al., 2013) and a two fouling mechanisms model to assess system performance and membrane fouling with single-staged, anaerobic fluidized membrane bioreactor (AFMBR) using PET beads as fluidized media for domestic wastewater treatment application. Organic removal efficiency and

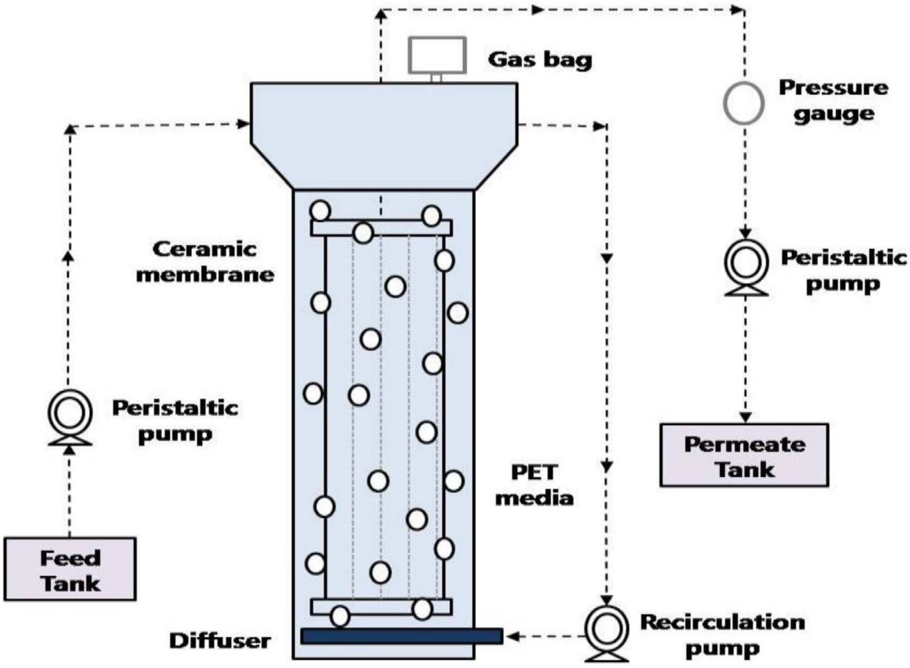

Fig. 1. Experimental set-up.