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Measurement of kinetic parameters in a submerged aerobic membrane bioreactor fed on acetate and operated without biomass discharge

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Abstract

The objective of this work was to study the biological performance of a submerged membrane bioreactor working with complete sludge retention that is susceptible to induce high biomass concentration and consequently low F/M ratio. A synthetic organic influent was used and the biological behavior of the system was studied for three different volumetric organic loads. In spite of continuous increase in the VSS concentration, a steady state in terms of removal efficiency and respiratory activity was achieved. High organic matter removal efficiency and no decline of the membrane performance were observed. Cycles of biomass synthesis and biomass loss by predation, lysis and decay could be considered so that a reduction of the biomass production seemed to be possible while keeping high treatment efficiency. Most of the cells were assumed to stay in a physiological state in which cell division was not favored, and the degraded substrate was essentially used to ensure maintenance requirements and storage products synthesis.

Keywords: Wastewater treatment; Immersed membrane bioreactors; Biokinetics; Bioconversion yield; Oxygen uptake rate; Sludge production

1. Introduction

The membrane bioreactor (MBR) combines a biological process, providing high removal efficiency, with a membrane separation stage, for perfect biomass/treated water separation. In the field of wastewater, research efforts have been directed (i) to obtain effluent of a high quality, suitable for water reuse [1,2], (ii) to analyze removal performances in relation to organic compounds and nutrients [1,3,4] or (iii) to optimize filtration performances by controlling fouling [5,6].

However, many challenges still remain, concerning in particular the hydraulic approach within the submerged capillary membrane systems, the control of metabolite production during operation, the accurate characterization of the biological species present and their interactions, and the definition of control tools (sensors and models) in the reactional and transfer processes.

The present work contributes to study of the behavior of this complex system. It focused on monitoring biological activity in a submerged membrane bioreactor treating an easily biodegradable organic substrate under constant fluxes. To better understand the behavior of the system in conditions of long residence time, susceptible to induce high biomass concentration, low F/M ratio and consequently low conversion yield [7–9], experiments were conducted with runtimes lasting several months, with a total biomass retention in the system, except for sampling.

Quantifying global pollution parameters, oxygen needs and biomass concentration in the system under different volumetric load conditions, led to propose different scenarios and process modelling necessary to control the metabolism and the system.

2. Materials and methods

2.1. Experimental unit and culture conditions

2.1.1. Experimental unit

Experiments were developed in an immersed membrane bioreactor of a total volume of 501 (Fig. 1). The reactor was ring-shaped, similar to an oxidation channel. A marine impeller was introduced to provide a horizontal circular flow of the suspension, preventing sedimentation of particles and favoring the homogenization of the media. The membrane bioreactor was

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Nomenclature

a'	exogenous respiration coefficient
b_h	decay rate of X_b (day^{-1})
f_p	fraction of inert particular COD generated in biomass lysis
f_{ps}	fraction of inert soluble COD generated in biomass lysis
i_{cv}	COD to VSS ratio ($g_{COD}\ g_{VSS}^{-1}$)
K_s	affinity constant for substrate of biomass ($g_{COD}\ m^{-3}$)
Q	feed flow ($m^3\ day^{-1}$)
S_{COD}	soluble chemical oxygen demand ($g_{COD}\ m^{-3}$)
S_i	inert soluble COD ($g_{COD}\ m^{-3}$)
S_s	biodegradable soluble substrate COD ($g_{COD}\ m^{-3}$)
S_{s0}	biodegradable soluble substrate in the influent ($g_{COD}\ m^{-3}$)
V	reactor volume (m^3)
X_b	active biomass ($g_{COD}\ m^{-3}$)
X_{COD}	particular chemical oxygen demand ($g_{COD}\ m^{-3}$)
X_i	inert particular COD ($g_{COD}\ m^{-3}$)
X_p	inert particular due to cells decay ($g_{COD}\ m^{-3}$)
X_s	slowly biodegradable particular substrate (COD) ($g_{COD}\ m^{-3}$)
Y	yield of COD or ($g_{COD_{formed}}\ g_{COD_{removed}}^{-1}$)
$Y_{obs.}$	observed yield of COD
Y'	yield of VSS ($g_{VSS}\ g_{COD}^{-1}$)

Greek letter

μ_{max}	maximum growth rate (day^{-1})

inoculated with a mixed culture taken from the sludge recirculation line of the wastewater treatment plant of Montpellier. Aeration was conducted by air injection through four-square plates placed on the bottom of the reactor, under the membrane modules. This injection provided oxygen for biological activity and created turbulence around the submerged membrane modules.

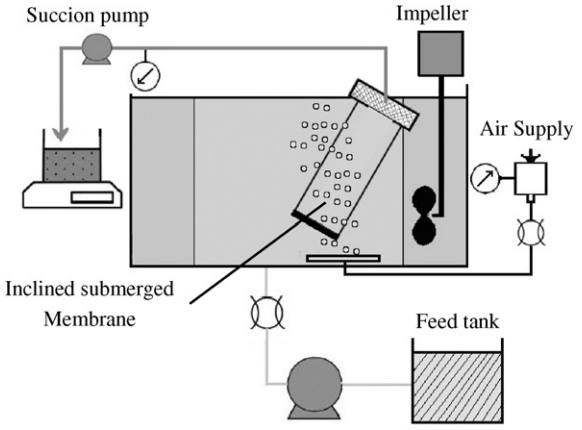

Fig. 1. Experimental set-up.

The reactor, similar to a continuous stirred tank, operated under aerobic conditions, steadily fed with a soluble and easily biodegradable synthetic organic substrate. Substrate feed and permeate extraction were respectively carried out by the peristaltic pumps (ISMATEC VC-MS/CA) and (WATSON MARLOW 505S), at constant rate. Temperature and pH were maintained in the reactor at respectively stable value of $20 \pm 1\ ^\circ C$ and 7.5 ± 0.5. The experiments were conducted under non-limiting oxygen conditions ($DO > 2\ mg_{O_2}\ l^{-1}$).

2.1.2. Synthetic effluent

The use of a synthetic medium made it easier to quantify kinetics rate in more accurate and reproducible conditions. Thus, the culture had to be fed with a soluble biodegradable effluent, composed of acetate as the source of carbon (neutralized acetic acid ($C_2H_4O_2$)), phosphate (dibasic ammonium phosphate ($(NH_4)2HPO_4$)) and nitrogen (ammonium nitrate (NH_4NO_3)). For all volumetric load conditions, nutrients were fed at a ratio of C/N/P = 150/15/1.

2.2. Analytical techniques

A number of analyses were carried out (Table 1) to determine the composition of the suspension, to control the operating parameters, to evaluate biological activity and to check the quality of the treated water. The treatment performance of the pilot plant and the development of the biomass concentration were followed in the effluent and in the reactor by determining total suspended solids (TSS), volatile suspended solids (VSS), soluble and particular chemical oxygen demand (S_{COD}, X_{COD}) and acetate concentrations. The supernatant was separated from the mixed liquor by filtration through 1.2 μm microfiber glass filters (GFC Whatman). Oxygen uptake rate (OUR) measurements were performed to follow the evolution of the respiration rate and to estimate the oxygen needs.

2.3. Experimental protocol

No biomass withdrawal was carried out, apart for sampling. The long-term treatment performance of the system was investigated for three volumetric organic loads: 0.41, 0.82 and $0.93\ kg_{COD}\ m^{-3}\ day^{-1}$, in order to study the biological behavior (physiological state of the biomass, growth kinetics, anabolic transformations) under conditions of high sludge age and total biomass retention. The overall operating conditions are given in Table 2.

Table 1
Measured parameters and analytical methods

Parameters	Methods
S_{COD}, X_{COD}	Hach methods
TSS, VSS	According to Ref. [10]
Acetate	Enzymatic Kit (Sigma)
Dissolved oxygen	Electrode Oxymeter WTW oxi 340
pH (T)	Hannah Instrument pH_{meter}