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Journal of Membrane Science 253 (2005) 217–232
journal of MEMBRANE SCIENCE
www.elsevier.com/locate/memsci

High rate sulfate reduction in a submerged anaerobic membrane bioreactor (SAMBaR) at high salinity

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Received 24 October 2003; received in revised form 24 October 2003; accepted 20 December 2004
Available online 21 March 2005

Abstract

Sulfate reduction in salt rich wastewaters (50 g NaCl L^{-1} and 1 g $MgCl_2 \cdot 6H_2O$ L^{-1}; conductivity 60–70 mS cm^{-1}) was investigated in a 6 L submerged anaerobic membrane bioreactor (SAMBaR) and inoculated solely with the halotolerant sulfate reducing bacterium *Desulfobacter halotolerans*. The SAMBaR was fed with acetate and ethanol at organic loading rates up to 14 g COD L^{-1} day^{-1} in excess of sulfate (COD/SO_4^{2-} of 0.5) and operated at pH 7.2 ± 0.2 and a hydraulic retention time (HRT) from 8 to 36 h. A sulfate reduction rate up to 6.6 g SO_4^{2-} L^{-1} day^{-1} was achieved in the SAMBaR operating at a flux of 17.1 L m^{-2} h^{-1}, which resulted in a HRT of 9 h including the backflow of permeate used for backflushing. The fairly constant very high specific sulfate reduction rate of 5.5 g SO_4^{2-} g VSS^{-1} day^{-1} showed that the performance of the SAMBaR was limited by the low amount of biomass (0.85 g VSS L^{-1}) present in the reactor at the end of the experiment. It was shown that sulfate reducing submerged anaerobic membrane bioreactors can be operated over extended periods of time without chemical cleaning of the membranes at a certain fixed flux if this flux is substantially below the nominal critical flux determined experimentally (18–21 L m^{-2} h^{-1}). Intermittent operation as well as backflush of the membranes were shown to slow the fouling in the membranes. Frequent backflush (e.g. 1 min each 10 min) is the suggested operational strategy to minimize fouling in anaerobic MBRs.
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Keywords: Sulfate reduction; High salinity; Submerged anaerobic membrane bioreactor; Halotolerant SRB; *Desulfobacter halotolerans*; Acetate; Ethanol

1. Introduction

Biomass retention is one of the most important aspects of modern anaerobic technology. Uncoupling of the hydraulic retention time (HRT) and cell retention time by self-aggregation (e.g. granular sludges) or biofilm formation is essential for the successful operation of conventional high rate anaerobic bioreactors [1,2]. Conventional anaerobic reactors, however, are less suited for the introduction of a particular metabolic capacity via the addition and retention of specialized microorganisms, as the added microorganisms mostly do not entrap or immobilize the granules or biofilms and are washed out from granular sludge or biofilm systems. The unsuccessful immobilization of specific strains into reactor biomass has been reported in fluidized bed [3], upflow anaerobic granular sludge bed (UASB) [4] and hybrid (UASB + packed bed) [5] reactor systems. A complete retention of all microorganisms in the bioreactor, including newly added bacterial species with a specific metabolic capacity, can be achieved in anaerobic membrane bioreactors. In addition, membrane bioreactors (MBR) are not dependent on granulation or biofilm formation, so that MBRs can also be operated with cell suspensions or flocs with poor settling characteristics. Thus, inoculation of the MBRs with a pure culture or a combination of known bacterial species can be performed without any risk of their washout. This is of particular interest for biological systems that depend on the retention of a large population of slow growing microorganisms that perform a specific metabolism, even at a very low HRT.

Anaerobic membrane bioreactors might offer advantages in terms of volumetric loading rates (resulting in a small foot-

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0376-7388/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.memsci.2004.12.032

print reactor), effluent quality and process stability [6]. In practice, anaerobic biomass can be sensitive to high salinity environments. High salt concentrations are known to significantly reduce the treatment efficiency of methanogenic and sulfidogenic conventional mesophilic [7,8] and thermophilic [9–11] anaerobic bioreactors. Indeed, high osmolarity environments trigger rapid fluxes of cell water, causing a reduction in turgor and dehydration of the cytoplasm [12]. Thus, the successful operation of sulfate reducing bacteria (SRB)-based bioreactors operating at high salinity requires the retention of halophilic SRB in anaerobic reactors.

The ability of halophilic anaerobic microorganisms to degrade different organic substrates has been reviewed and appears that only a few easily degradable substrates such as simple sugars and amino acids can be fermented via dissimilatory sulfate reduction [13,14]. The upper limit of salinity at which dissimilatory sulfate reduction has been observed is 240 g NaCl L^{-1}, for the incomplete lactate, ethanol and pyruvate oxidizer *Desulfohalobium retbaense* [15]. The highest salinity for the complete oxidation via sulfate reduction reported so far is around 130 g NaCl L^{-1} for the acetate oxidizer *Desulfobacter halotolerans* [16]. The incorporation of such a halophilic SRB in a membrane bioreactor would greatly extend the application of desulfurization to wastewater treatment systems that can presently not be treated biologically.

The aim of this work was to assess the performance of a sulfate reducing submerged anaerobic membrane bioreactor (SAMBaR) fed with acetate and ethanol as the sole electron donors operated at high salinity (50 g NaCl L^{-1} and 1 g $MgCl_2{\cdot}6H_2O$ L^{-1}; conductivity 60–70 mS cm^{-1}) and inoculated with the pure culture *Desulfobacter halotolerans*. The major limitation to the use of membranes is the continuous reduction in permeate flux by membrane fouling and the operational costs associated with it [17]. The reduction in permeate flow is known to be the main factor in determining the economic feasibility of membrane processes [17]. Therefore, different operational procedures for the minimization of fouling were studied, including the determination of the critical flux and the assessment of the influence of flux stoppage and membrane backflush on the increase in transmembrane pressure (TMP).

2. Materials and methods

2.1. Continuous experiments

2.1.1. Experimental setup

A submerged anaerobic membrane bioreactor (SAMBaR) of 6 L (1 m high, internal diameter 10 cm) was operated during 92 days in order to study the feasibility of high rate sulfate reducing processes at high salinity (50 g NaCl L^{-1} and 1 g $MgCl_2{\cdot}6H_2O$ L^{-1} in the influent; 60–70 mS cm^{-1}). The SAMBaR (Fig. 1) was equipped with a set of five cylindrical polysulfone membranes (Triqua B.V., Wageningen, The Nethelands) with a total effective surface of 0.07 m^2 (Fig. 1). The mean pore size of 0.2 μm guaranteed the uncoupling of the hydraulic retention time (HRT) and the cell retention time. The SAMBaR was equipped with a double wall, through which water, heated in a thermostatic waterbath (Julabo, Seelbach, Germany), was recirculated to maintain the reactor temperature at $33 \pm 1\,^{\circ}C$. This temperature was selected because it is the optimum temperature for the growth of *Desulfobacter halotolerans* [16], used as reactor inoculum.

The pH in the reactor was maintained at 7.25 ± 0.2 (within the optima pH range for growth of *Desulfobacter halotolerans*, [16]) by means of an automatic pH control, adding HCl (1 M) when necessary (Fig. 2B). The pH was measured

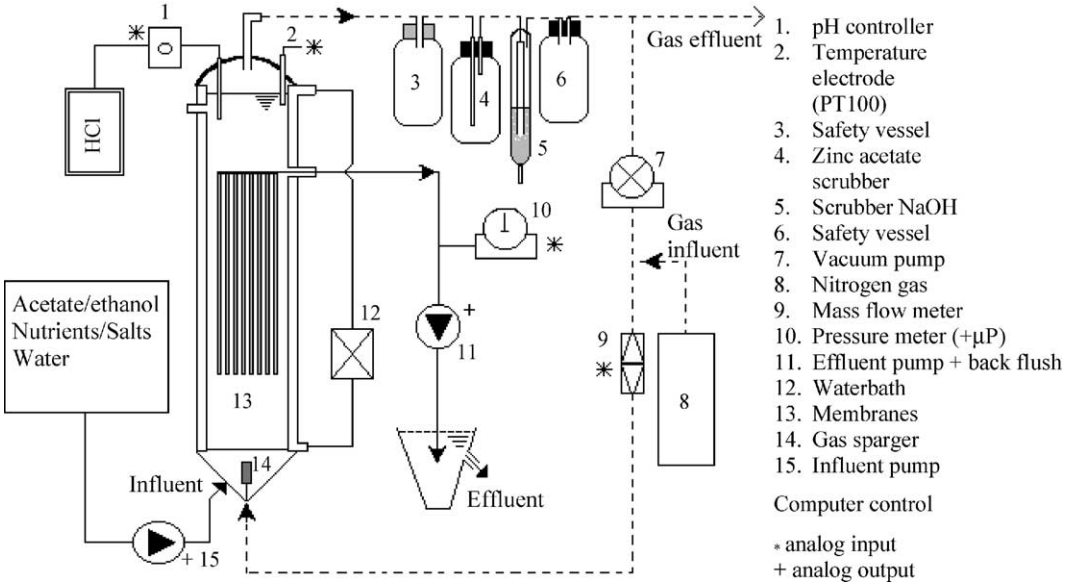

Fig. 1. Schematic representation of the submerged anaerobic membrane bioreactor (SAMBaR).

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