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# Optimisation of dead-end filtration conditions for an immersed anoxic membrane bioreactor

E.J. McAdam, S.J. Judd *

*Centre for Water Science, Cranfield University, Bedfordshire, MK43 0AL, UK*

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ABSTRACT

The optimisation of the energy demand in the application of dead-end filtration in an immersed membrane bioreactor applied to groundwater denitrification has been studied. Filtration cycle length was varied at a set flux to control the amount of foulant deposited at the membrane surface. Physical cleans comprising a simultaneous backflush and gas injection were subsequently instigated and the reversibility of the deposit determined by the residual resistance, $R_{res}$. Examination of $R_{res}$ versus flux and cycle length variation indicated an operational envelope where limited fouling occurred. The transition from limited fouling to extensive fouling was indicated by a parameter based on the critical accumulated mass, indicating incipient deposit consolidation. The transition between regions became less severe when the solids retention time was increased from 10 to 25 and 40 days. This was apparently related to a shift in bulk physical characteristics. Nevertheless, low residual fouling was observed during long-term filtration when operating below the critical mass, resulting in a 20× reduction in energy demand over that of constant gas injection.



## 1. Introduction

Groundwater nitrate levels in many areas now exceed regulatory limits [1]. Treatment is commonly by ion exchange which selectively extracts nitrate from the source water and subsequently produces a concentrated brine waste stream of up to 2% of the influent flow. Biological denitrification using membrane bioreactors (MBRs) represents a technically attractive alternative treatment, since an inert product (nitrogen gas) is produced whilst the process also provides a physical barrier for separating the biomass from the product water.

To maintain biochemical reduction, dissolved oxygen (DO) should remain below 0.1 mg $L^{-1}$. Consequently, nearly all previous pressure driven membrane bioreactor research has focused on external [1–3] (or sidestream) rather than immersed configured MBRs. This circumvents the requirement for air scouring of the membrane, which otherwise greatly improves the energetic efficiency of the configuration over that of the sidestream [4]. Reducing air scour (to ~5 s every 10 min) so as to sufficiently reduce DO levels (<0.1 mg $L^{-1}$) to maintain anaerobic conditions has been shown to provide insufficient shear to control fouling in an immersed anaerobic MBR [5]. The use of recycled nitrogen gas for membrane scouring has been successfully demonstrated [6], but in this study gasification was on a 10 s on per 10 s off basis. Since gas pumping makes up 30–40% of the overall energy demand [7], and the use of recycled nitrogen from the reactor headspace presents a significant process modification challenge, it is of interest to seek other means of maintaining membrane permeability.

The current paper explores hydrodynamic optimisation of immersed hollow-fibre membranes for the groundwater denitrification of by an immersed MBR employing intermittent dead-end filtration. The study specifically addresses:

(a) minimisation of the energy demand required for gas scouring by limiting its application,
(b) deposit reversibility (and thus permeability recovery),
(c) the deposit formation mechanism, and
(d) operational stability with respect to solids retention time (SRT) variation.

## 2. Material and methods

### 2.1. Filtration rig

Biomass was initially adapted to anoxic conditions in batch mode. The 75 L reactor (Fig. 1) was subsequently seeded at a ratio 10:1. The influent nitrate concentration was set at 22.6 mg $NO_3^-$–N $L^{-1}$, approximately equivalent to mid-way between the

* Corresponding author.
*E-mail address:* s.j.judd@cranfield.ac.uk (S.J. Judd).

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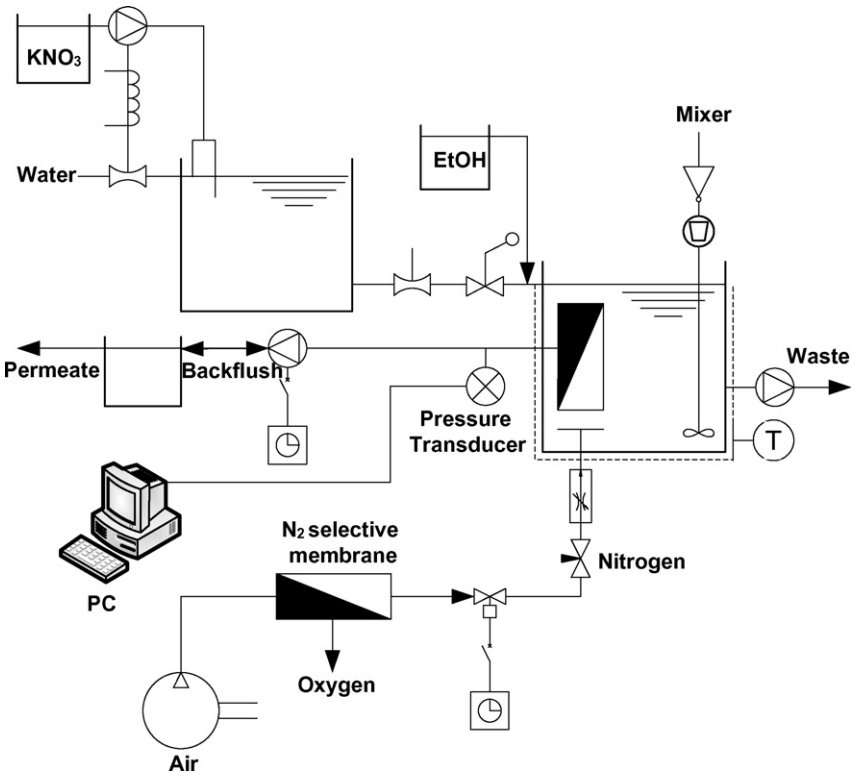


**Fig. 1.** Experimental setup.

mean and peak nitrate loads experienced in full-scale applications [1]. Ethanol was supplied as the exogenous substrate and dosed at a previously defined optimum C:N ratio of 1.45 [8]. Reactor temperature was maintained around 20 °C using a thermostatically controlled heating jacket. Biomass distribution was ensured through impeller mixing below the membrane module at a speed of 30 rpm creating a root mean square velocity gradient ($G$) of 12.8 $s^{-1}$, and the shear imparted to the membrane from this mixing was demonstrated as being negligible. The hydraulic residence time (HRT) was ~6 h. The SRT in successive tests was set at 10, 25 and 40 days. The process was allowed 3 SRTs to arrive at steady state prior to testing.

A 0.93 $m^2$ out-to-in immersed PVDF hollow-fibre membrane with 0.04 μm nominal pore size was used. Permeate was withdrawn under suction from the membrane using a piston pump (FMI Inc.) operated in both forward and reverse motion in accordance with a digital programmable relay (Allen and Bradley, 700-HX). To avoid the entrainment of air, nitrogen enriched air (>99%) was used to scour the membrane, produced from compressed air (8 bar g) using a nitrogen selective hollow-fibre membrane ($N_2$ Gen Ltd., 5-M). Gas was introduced using a solenoid valve (Zoedale Plc) controlled with a programmable digital relay (Kübler Gmbh) and its flow rate controlled with a needle valve. Pressure was monitored using a pressure transducer (Gem Sensors, UK) whose signal was recorded with a data logger (Pico technology, ADC-16).

### 2.2. Analysis

Mixed liquor suspended solids (MLSS) were determined by standard methods. DOC was measured using a Shimadzu TOC-5000A analyser. Particle size was measured with a Malvern Mastersizer 2000, and a Malvern Zetasizer (Malvern, UK) used to perform zeta potential measurements. Since the zeta potential of biomass flocs could not be measured directly the flocs were agitated and the charge of the supernatant determined [9]. Soluble microbial products (SMP) were extracted according to the method described in Judd [10], and carbohydrate and protein content respectively determined using the phenol–sulphuric acid method [11] and Lowry method [12]. Absorbance was measured using a Jenway 6505 UV–vis spectrophotometer at $UV_{480nm}$ and $UV_{750nm}$ absorbance, respectively using D-glucose and bovine serum albumin (BSA) as standards for protein and carbohydrate.

### 2.3. Sampling protocol

Cyclic filtration was conducted in dead-end mode. The quantity of solids deposited on the membrane was varied by varying cycle duration (5, 10, 20, 30, 45, 60 and 90 min). To characterise residual (irreversible) fouling, cyclic filtration was continued for ~24 h up to a set filtered volume (equivalent to 350 L $m^{-2}$ membrane area). Between cycles, a low energy physical clean was applied to remove the reversible layer comprising a simultaneous 30 s backflush at the same rate as the operating flux and gas injection at a specific gas demand ($SGD_m$) of 0.39 $Nm^3$ $m^{-2}$ $h^{-1}$ per unit membrane area. The remaining resistance was considered to be the irreversible layer [13]. Following each run, the membrane module was removed, rinsed and soaked in NaOCl (500 mg $L^{-1}$) for 5 h. During this period, a spare module was inserted to maintain stable operation. After chemical soaking, the module was rinsed with clean water and the permeability assessed to assure recovery.

### 2.4. Data Analysis

Residual fouling for the overall filtration period up to 350 L $m^{-2}$ was calculated from the initial pressure at the start of each cycle (Fig. 2). Residual resistance, $R_{res}$, from the same filtration period