Desalination 250 (2010) 815–818

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Optimising mixing and nutrient removal in membrane bioreactors: CFD modelling and experimental validation☆

M. Brannock [a,*], G. Leslie [a], Y. Wang [a], S. Buetehorn [b]

[a] UNESCO Centre for Membrane Science and Technology, University of New South Wales, Sydney, Australia
[b] Department of Chemical Engineering, RWTH Aachen University, Aachen, Germany

ARTICLE INFO

Article history:
Accepted 5 November 2008
Available online 9 October 2009

Keywords:
CFD
Computational fluid dynamics
MBR
Membrane bioreactor
RTD

ABSTRACT

Membrane Bioreactors (MBRs) have been used successfully in biological wastewater treatment to solve the perennial problem of effective solids–liquid separation. The optimisation of MBRs requires knowledge of the membrane fouling, mixing and biokinetics. MBRs are designed mainly based on the biokinetic and membrane fouling considerations even though the hydrodynamics within an MBR system is of critical importance to the performance of the system. Current methods of design for a desired flow regime within the MBR are largely based on empirical techniques (e.g. specific mixing energy). However, it is difficult to predict how vessel design in large scale installations (e.g. size and position of inlets, baffles or membrane orientation) affects hydrodynamics, hence overall performance. Computational Fluid Dynamics (CFD) provides a method for prediction of how vessel features and mixing energy usage affect the hydrodynamics and pollutant removal and subsequently allowing optimisation of MBR design and performance. In this study, a CFD model was developed which accounts for aeration and biological nutrient removal. The modelling results are compared against experimental results of two full scale MBRs for the hydrodynamics and against a modelling benchmark for the biological nutrient removal component of the model.

1. Introduction

Membrane Bioreactors (MBRs) have been successfully used in biological wastewater treatment to solve the perennial problem of effective solids–liquid separation. Conventional wastewater treatment systems use solids settling methods for separation, however these processes are difficult to control and can produce highly variable effluent quality [1]. MBRs on the other hand use membrane micro filtration combined with biological treatment consistently produce very high quality effluent. For this reason, MBRs are an excellent opportunity to simultaneously manage municipal wastewater while producing valuable recycled water to meet the current water crisis [2].

The design and optimisation of MBR units requires knowledge of membrane fouling, mixing and biokinetics. However, MBR design is mainly based on the biokinetic and membrane fouling considerations even though the hydrodynamics within an MBR system is of critical importance to the performance of the system. Current design methods make it difficult to predict how vessel design (e.g. position of inlets or baffles) affects hydrodynamics, hence overall performance. Computational Fluid Dynamics (CFD) provides a method for prediction of the effect design features have on the hydrodynamics from a fundamental level. The MBR CFD model presented here couples the liquid and gas hydrodynamics.

1.1. Site description

Two full-scale MBRs located in Australia were examined for this work, one having hollow fibre membranes and the other having flat sheet membranes. Site 1 is a flat sheet (FS) membrane MBR. It is the primary sewage for the local township and provides recycled water for the surrounding region. The plant, which consists to process streams in parallel, is sized to treat an Average Dry Weather Flow of 3.4 ML/d (1.7 ML/d each stream) and is designed for nutrient removal via simultaneous nitrification/denitrification (SND). See Fig. 1 for a diagram of the process streams examined; the Site 1 (FS) MBR is comprised one of the two parallel process streams. Table 1 gives an overview of the operating process parameters during the experimental study while Tables 2 and 3 summarise the biological performance of the MBRs. Site 2 is a hollow fibre (HF) membrane MBR and operates at large sewage treatment plant (STP). It receives primary treated sewage from the STP and produces recycled water for the site and local area. The plant is sized to treat 2 ML/d of influent and is designed for nutrient removal so it possesses an anoxic zone, aerobic zone and an internal recycle (see Fig. 1).

2. Methods

Residence time distributions (RTD) have been used here to describe the mixing of the MBRs examine. RTDs are a probability distribution of times that fluid elements may stay within a system. This is important as it is the length of time a fluid parcel stays within a

☆ Presented at the Conference on Membranes in Drinking and Industrial Water Production, 20–24 October 2008, Toulouse, France.

* Corresponding author.
E-mail address: matthew.brannock@worleyparsons.com (M. Brannock).

0011-9164/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.desal.2008.11.048

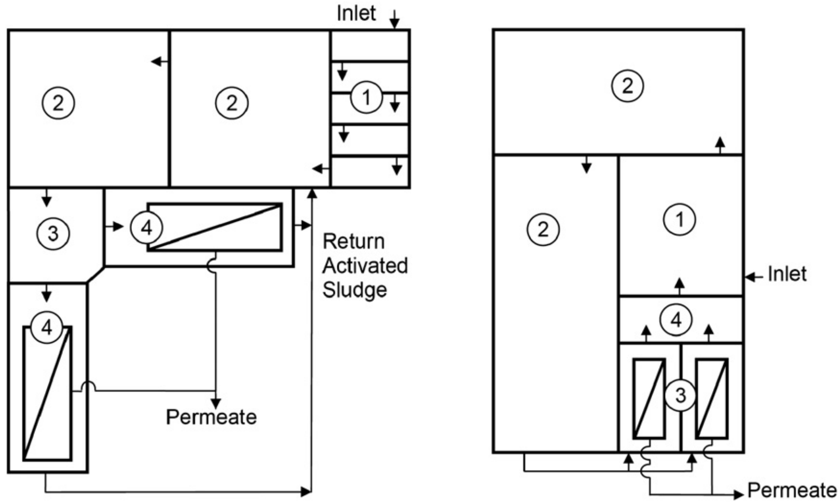

Fig. 1. Overview of the process setup: Site 1 (FS) MBR (left) — 1. Bioselector, 2. Swing aerobic and anoxic zones, 3. Aerobic zone, 4. Membrane filtration vessel; Site 2 (HF) MBR (right) — 1. Anoxic zone, 2. Aerobic zones, 3. Membrane filtration zone, 4. De-aeration zone.

reactor system which in turn determines the degree of pollutant removal. The sub-sections below describe the experimental and modelling methods which were used to measure the full-scale MBR RTDs, and therefore characterise the mixing and potential pollutant removal. The experimentally determined RTDs are subsequently used to validate the developed hydrodynamic model. An in depth study of the experimental results is also made in terms of energy usage and the effect on mixing in the MBRs studied.

2.1. Experimental methods

Tracer studies are used to experimentally measure the RTD in each full-scale vessel. These were carried out using a pulse input of lithium chloride delivered at the MBR inlet (post-screening) with the tracer response being measured in the permeate and other relevant sample points. Lithium chloride is commonly used for tracer studies of wastewater processes due to its inert nature [3–5]. The amount of tracer used corresponded to a bulk concentration of 1.5 mg Li^+/L (i.e. mass of lithium is divided by volume of the MBR). This ensured that the tracer response is much greater than the detection limit of the analysis technique. The Li^+ concentration was measured using ICP-AES (Inductively Couple Plasma – Atomic Emission Spectrophotometry) and had a detection limit of 0.008 mg Li^+/L.

Dosing solutions were prepared with concentrations of 40–60 g Li^+/L and a maximum dosage volume of 25 L; this ensured a small dosage volume, low dosage time yet at a small density difference between the dosage solution and mixed liquor. The dosage solution was pumped in at approximately 75 L/min over 20 s into the inlet stream. For Site 2 (HF) MBR this is 0.02% of the HRT and for Site 1 (FS) MBR is 0.004% of the HRT.

Table 1
Operating process parameters of the two MBRs during each trial.

Parameters	Units	Site 1 (FS) MBR	Site 2 (HF) MBR
Average influent flowrate	Ml/d	1.1	1.1
Total volume of bioreactor vessels	m^3	852	435
Total volume of membrane filtration vessels	m^3	392	36
MLSS	g/L	11.3	5.0
Membrane type	–	Flat sheet	Hollow fibre
Net membrane flux	L/m^2/hr	11.8	29.0
Mixed liquor return flowrate	m^3/hr	461	433
Sludge age	days	16.6	9.9
Air flowrate into bioreactor	Nm^3/hr	109	419
Air flowrate into membrane filtration vessel	Nm^3/hr	992	918

This enabled effectively instantaneous delivery of the tracer. To obtain reproducible results at both sites, the tracer studies were undertaken with as many constant process parameters possible. The intermittent influent flow and the switching on/off of the aeration were still experienced. The tracer studies commenced at exactly the same time of the day. Sampling was undertaken for four hydraulic residence times ensuring close to 100% tracer recovery.

2.2. Modelling methods

2.2.1. Fundamentals of CFD

CFD modelling formulates and solves the fundamental mass and momentum balance equations using numerical techniques. These fluid-flow equations, known as the Reynolds-averaged Navier–Stokes equations, are non-linear and cannot be solved analytically in almost all cases. To solve the equations they must be linearised and solved over many small control volumes (the computational mesh). For determination of the flow-field these simulations require input of geometry, boundary conditions and fluid properties.

2.2.2. Proposed MBR CFD model

Before construction of the MBR CFD model, a conceptual model was developed. The proposed CFD model (see Fig. 2) is composed of the core hydrodynamics model for the liquid and gaseous phases, coupled with the sludge and species transport equations.

This conceptual model has been adapted from previous work undertaken by Brannock [6] where it was used for the CFD simulation of liquid hydrodynamics coupled with sludge transport in a mixed anoxic

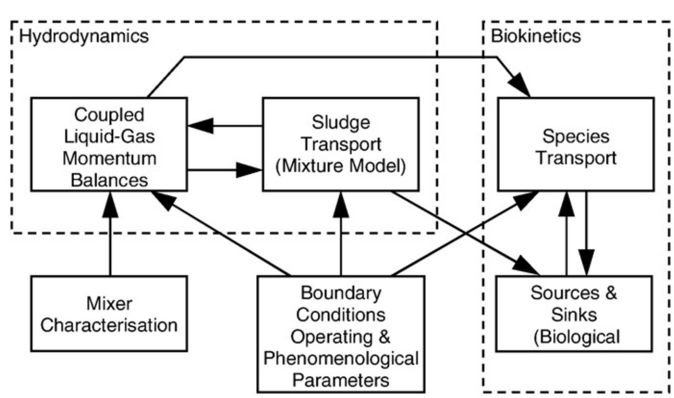

Fig. 2. Schematic of proposed CFD model components.