Journal of Membrane Science 321 (2008) 264–271

Contents lists available at ScienceDirect

Journal of Membrane Science

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

Local hydrodynamic investigation of the aeration in a submerged hollow fibre membranes cassette☆

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ARTICLE INFO

Article history:
Received 7 September 2007
Received in revised form 24 April 2008
Accepted 2 May 2008
Available online 8 May 2008

Keywords:
Submerged membrane bioreactor
Hollow fibre
Aeration
Hydrodynamics
Bi-optical probe

ABSTRACT

The better understanding of the effective air distribution inside a membrane cassette is a particular challenge in submerged membrane bioreactor. The present study is the first one that investigates the hydrodynamics of the coarse bubbles flow inside a hollow fibre membranes cassette. The experimental investigations were carried out in a reactor equipped with commercial modules from ZENON ZeeWeed® 500d. A bi-optical probe was used to measure the bubble size, the bubble velocity and the gas hold-up at different locations between the modules and for three different gas flow rates. These local measurements gave significant information about the lateral distribution of the air and its evolution with the height on the surface of the membrane modules, which can impact on the filtration performance and are the first step to an optimisation of the aeration system and module geometry.

1. Introduction

The increasing stringent environmental legislation affecting both sewage treatment and industrial effluent discharge is one of the major drivers for the development of membrane bioreactors (MBRs). Even though MBRs are already established in commercial application for more than a decade, fouling, clogging and sludging remain the most crucial issues limiting it application.

The effect of gas sparging on hollow fibre membrane systems has been largely investigated and it is now well known that the introduction of a second phase increases the permeate flux of this system [1–4]. Despite the progress in terms of system design and operation in the past years, membrane aeration still contributes significantly to the energy demand. The design and optimisation of the aeration requires knowledge on the effective distribution of air in the whole membrane cassette, which impacts on the membrane permeability and sustainable applied fluxes. Improving the hydrodynamics within the filtration unit could reduce the aeration requirement and increase the filtration performance.

Design and optimisation of the aeration system can be achieved using computational fluid dynamics (CFD) simulation. To date, to the author's knowledge, there are no CFD studies investigating the hydrodynamics within submerged membrane systems that validate their results based on experimental data inside the membrane cassette, due to the difficulty to access this zone with most of measuring technique. The validation of the flow field between the membranes modules is however of high importance since this parameter contributes to the efficiency of the process.

The objective of this study is to characterize the flow inside a commercial submerged hollow fibre membrane cassette. An optic-probe is used to measure the local gas hold-up, local bubble size and local bubble velocity between the modules, where the other technique such as photography and image analysis cannot access. The present study shows how local measurements can help to improve understanding of the two-phase hydrodynamics in submerged MBRs module. This set of local flow data will be used in a further study to develop and validate a two-phase flow CFD model applied on submerged MBR system.

2. Materials and methods

2.1. Experimental set-up

The experimental setup consists of a rectangular reactor tank with the dimension $z = 3.15$ m, $y = 0.60$ m, $x = 1.00$ m (Fig. 1). The tank is equipped with one ZENON ZeeWeed® 500d cassette made

☆ A part of this work was Presented at the IWA, Particle Separation Conference, Toulouse, France, 9–12 July 2007.

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0376-7388/$ – see front matter
doi:10.1016/j.memsci.2008.05.001

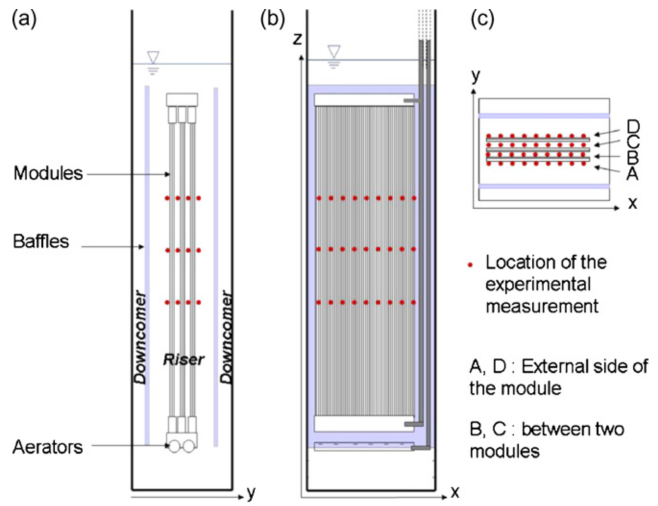

Fig. 1. Schematic of the experimental set-up: (a) front view, (b) side view and (c) top view.

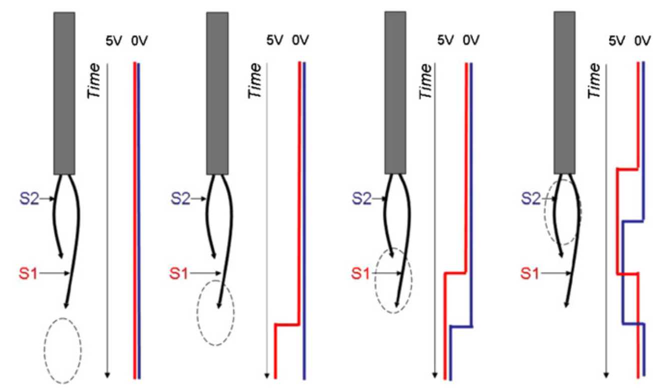

Fig. 2. Schematic of the experimental optic probe.

of three ultra-filtration modules. Each module consists of a bundle of hollow fibre membranes and the total membrane surface area is equal to 95 m^2. The membrane fibres are tightly held, that means that the fibres cannot move laterally, in order to protect the measuring probe sensor. Three PVC pipes can collect the permeate at the top and the bottom of each module. Sparging flow along the membrane surface is created by coarse bubble aeration at the bottom of the membranes. The air is introduced through two perforated pipes with holes of 6 and 8 mm, connected to a blower which allows an air flow rate up to 90 Nm^3/h. The reactor has a particular configuration due to the introduction of two baffles on each lateral side of the cassette. The distance between the baffle and the module is equal to approximately 15 cm. The distance between two modules is approximately equal to 5 cm. The so-called airlift reactor is divided into two vertical zones connected at the top and the bottom. The riser is the zone where the gas is sparged and the resulting gas hold-up difference between the gas sparged riser and the unsparged downcomer leads to a difference in the bulk densities of the fluid in the two zones and induces fluid circulation. Upflow occurs in the riser, and downflow in the downcomer (Fig. 1a). This study was run with tap water and air without filtration because the main objective is to characterize the flow induced by the aeration. A further study will be carried out with the filtration in order to determine the impact of the filtration on the general two-phase flow hydrodynamics, and also with mixed liquor instead of pure water.

2.2. Gas phase characteristics

A double optical probe is made of two sensitive extremities. Phase detection is possible due to the different refraction indexes of gas and liquid. An infrared light is injected into each glass fibre and reaches the extremity of each probe. This light is reflected when the glass fibre extremity lies in gas and refracted when it lies in liquid. The light signal is converted to electric signal in an optoelectronic apparatus: 5 V for the air and 0 V for the liquid (Fig. 2). Both signals are then processed to give the local void fraction, the vertical velocity as well as the diameter of the bubbles.

Simmonet et al. [5] validated the local void fraction measured by the optical probe by comparing the global void fraction calculated from pressure measurements and the local value given by the probe. Considering a homogeneous regime, these two techniques should give nearly equal result. He found a satisfying agreement between the two methods. Concerning the bubble velocity, the author checked this parameter by comparison with high-speed camera and an uncertainty about 15% was found. Madec [2] compared the results obtained using a double optical probe with results obtained using image processing on a turbulent bubbly flow. He found that the mean cord measured by the double optical probe can be slightly overestimated due to the fact that the small bubbles can be deviated by the liquid flow before reaching the tips of the optical probe. Chaumat et al. [6] investigated the two-phase flow in a bubble column under high gas and liquid flow rates with large bubbles and estimated the bubble velocity using the most probable velocity method (see Eq. (2)). She compared the space averaged gas velocity calculated through the integration over a column section to the superficial gas injected in the column and found that the optical probe overestimates the bubble velocity of about 20%. She explained the error due to the bad detection by the optical probe of the very short bubbles.

Although the values given by the probe are not very precise yet, this method allows a better knowledge of the complex flow in large bubble columns at high gas hold-up, and is easy to settle. This technique was used in many studies to measure the characteristics of the gaseous phase in bubble column and airlift reactor [7–12].

Each glass fibre can determine the local void fraction ε, or local fraction of the air. It is calculated as the ratio between the gas time of one glass fibre and the duration of the recording (Eq. (1)). However, only the value given by the upward glass fibre is taken into consideration due to the possibility of misevaluation from the second glass fibre because of possible deviated motion of the bubble when it interferes with the first tip.

$$\varepsilon = \frac{\sum t_{\mathrm{bubble},i}}{t_{\mathrm{total}}} \qquad (1)$$

where $t_{\mathrm{bubble},i}$ is the total time of the glass fibre in the gas (s) and t_{total} is the duration of the recording (s).

The bubble velocity v_b (Eq. (2)) is the time taken by a bubble to cover the length between the two-glass fibres l_{12}. Its calculation is based on the most probable time migration directly issued from the inter-correlation function between the two signals:

$$v_b = \frac{l_{12}}{\text{most probable time migration}} \qquad (2)$$

The value calculated is therefore the most probable bubble velocity [13].

The maximum of the inter-correlation function, c, is a parameter, which gives an indication on the relevance of the bubble velocity calculated. The inter-correlation analysis is based on the hypothesis that if all the bubbles interfere with the two tips, without any perturbation, the signal coming from the second tip should be a