



Bubbles in spacers: Direct observation of bubble behavior in spacer filled membrane channels

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ARTICLE INFO

Article history:

Received 29 September 2008

Received in revised form 8 January 2009

Accepted 24 January 2009

Available online 5 February 2009

Keywords:

Spacer

Two phase flow

Air sparging

Spiral wound module

Optical system

ABSTRACT

Air sparging is a means to prevent biofouling and scaling in hollow fibers and tubular membranes. Little is known for the case of bubbles flowing in spacer filled channels. We first demonstrate that the flow of bubbles in feed channels prevents biofouling. Then we describe a method to quantify the hydrodynamics of bubbles for various spacers, liquid and gas velocities. The bubble size at a given Reynolds number is similar for the six spacers under investigation. At low liquid velocities (<0.15 m/s) the bubbles are elongated in the direction of flow. With increasing liquid velocity, bubble sizes become smaller and the bubbles are more spherical. The bubble diameter remains large enough to be in contact with both walls, which is required for efficient fouling reduction. The membrane area coverage of bubbles from a single source shows a maximum at intermediate liquid velocities: at low velocity the bubbles follow a single path dictated by spacer geometry and presence of stagnant bubbles; at high speeds the bubbles follow a straight path from the inlet to the outlet. At intermediate speeds, less stagnant bubbles are present and the moving bubbles deviate from the single path followed at low liquid velocities, which increases the membrane area coverage.

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1. Introduction

With increasing drinking water scarcity, the need for desalination of brackish and seawater is increasing [1]. This requires the development of new plants with high capacity, high salt rejection and low operating costs. Membrane fouling and concentration polarization (CP) are two factors that reduce the flux of membrane systems in time. Intensive pre-treatment is required to prevent biofouling and scaling. At some moment in time, the membranes need to be cleaned, either mechanically (backwashing, high cross-flow velocity) or chemically. This increases the operational costs and can decrease the capacity of existing installations [2]. Several options are available to decrease fouling and/or concentration polarization: pre-treatment of the feed (with ultrafiltration for example), increasing the cross-flow velocity, introduction and optimization of turbulence promoters and air sparging. This latter technique seems promising in both tubular, hollow fiber and flat sheet or spiral wound modules [3]. Research on the use of air sparging in tubular and hollow fiber modules is widely available, in flat sheet modules however it is mainly limited to empty channels.

Previous studies have shown that concentration polarization or fouling needs to be the limiting step in the process for air sparging to be effective. Air sparging is unable to increase the permeation in other cases [4,5]. Furthermore, the bubbles need to be close to the membrane to be effective. For all systems this means the bubbles need to be large enough to fill more than 60% of the diameter (HF and tubular systems) or channel height (flat sheet modules) [6]. The bubbles need to reach the total membrane area to be most effective. Maldistribution of the bubbles will decrease the effectiveness of this technique [7,8]. Since spacers are among other things used to improve the distribution of liquid over the membrane module, the presence of spacers is also expected to increase the effectiveness compared to empty channels.

So far, only two articles are available that describe bubble flow in flat sheet modules filled with spacer-like structures in detail [7,10], despite the fact that this technique is known to improve the performance of spiral wound modules [9,11] as shown in Fig. 1. The authors report that the use of baffles improves the distribution of the bubbles and prevents coalescence of the bubbles while the bubbles still remain large enough to be effective. Net type spacers are widely used in spiral wound modules but no detailed study of bubble flow in these structures was available.

We investigated the behavior of bubbles in spacer filled channels as these are expected to improve the distribution of the bubbles

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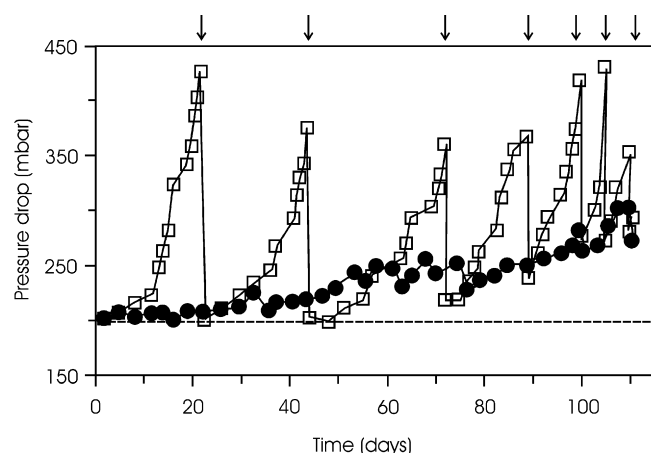


Fig. 1. Pressure drop development for a module with (circles) and without (squares) daily air water cleaning, redrawn after [9]. Arrows indicate incidental air cleaning of the reference element.

as well. To visualize the beneficial effect of continuous air sparging preliminary biofouling experiments are reported. Furthermore the influence of liquid and gas flow velocity, spacer geometry and material on the size, shape, velocity and distribution of the bubbles and pressure drop over the module will be presented for a lab-scale flat sheet module with an optical system tracking the bubble size, shape and path. These experiments provide the first details on bubble flow in spacer filled channels and provide a starting point for understanding the increased performance of air sparged spiral wound modules.

2. Experimental

2.1. Setup

All bubble behavior experiments were performed with the setup shown in Fig. 2. It consists of a liquid pump (Verder pumps, Leeds, UK), two pressure sensors (Keller AG, Winterthur, Switzerland), a mass flow controller (Brooks Instruments, Veenendaal, The Netherlands) for the gas flow and a flow cell. The flow cell is custom made from 1 cm thick PMMA plates and has a rectangular channel of 5 cm × 15 cm for the flow. Channel height is determined by the thickness of the spacer between the plates. The spacers used in this study and their dimensions are given in Table 1. Porosity and hydraulic diameter were calculated according to Ref. [12]. The channel is positioned vertically for all experiments. Liquid enters through 1 mm holes (2 mm apart) approximately 5 mm from the bottom of the channel, and exits via a similar arrangement 5 mm from the top of the channel. Gas enters the cell via a single 1 mm hole located 25 mm from the channel bottom. Liquid velocities were varied between 0.05 m/s and 0.7 m/s, with gas velocity constant at 0.05 m/s. All experiments were performed at room temperature. Since the permeate flow in RO is very small compared to the cross-flow velocity [13], the cell was operated without permeation or even a membrane. Experiments confirmed that the presence of a

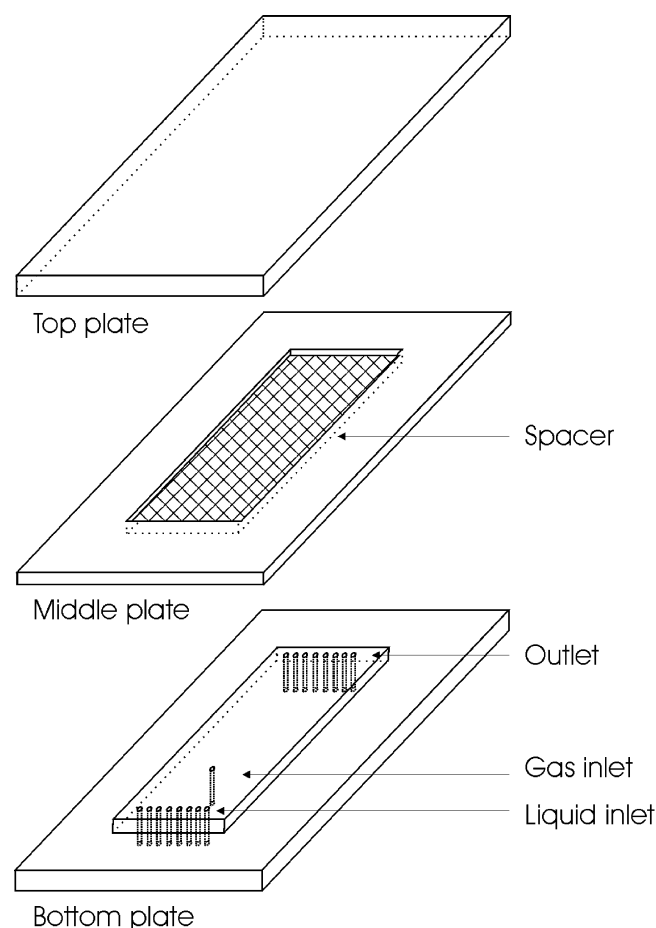


Fig. 2. Schematic representation of the flow cell.

polyamide DOW SW30HR membrane did not influence the bubble size or shape.

Two phase flow was observed with a CCD camera (Pixelfly VGA, PCO AG, Kelheim, Germany) connected to a PC. The camera was fitted with a fixed focal length lens (Edmund Optics, York, UK) with a minimum working distance of 30 cm. This system allowed a maximum frame rate of 50 Hz at a resolution of 640 × 480 pixels, which resulted in 3–4 pixels per millimeter of the flow cell at the applied working distance. In order to obtain constant light intensity in the cell, it was illuminated from above with a cold light source (Euromex microscopen BV, Arnhem, The Netherlands).

2.2. Materials

Nitrogen from a central supply was used as the gas phase, the liquid phase was demineralized water. To improve the contrast between the liquid and gas phase, brilliant blue R (Acros organics, Geel, Belgium) was added to the water. The surface tension of

Table 1
Overview of (non-woven) spacers used.

Name	Thickness (mm)	Filament angle (°)	Filament spacing (mm)	Hydraulic diameter (mm)	Porosity (–)	Material	Type
A	0.51	90	1.59	0.59	0.87	pp	no2016_90pp
B	0.52	60	1.69	0.58	0.86	nylon	no2015_60pa
C	0.68	85	2.80	0.89	0.90	pp	NA
D	1.17	90	3.63	1.36	0.87	pp	nfnb214
E	1.96	60	4.23	1.68	0.79	pp	no8006_60pp

A, B and E supplied by Naltex/Delstar Inc., D supplied by Conwed Plastics, C is from an unknown supplier. PP = polypropylene.

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