Process Intensification of Gas-Liquid Flows with a Novel Constricted Oscillatory-Meso Tube

Nuno Reis[a,*], Pedro Mena[b], Fernando Rocha[b], António Vicente[a], José Teixeira[a]

[a] *University of Minho, IBB – Institute for Biotechnology and Bioengineering, Centre for Biological Engineering, Campus de Gualtar, 4710-057 Braga, Portugal, nunoreis@deb.uminho.pt*

[b] *University of Porto, Faculty of Engineering, Department of Chemical Engineering, Institute for System and Robotics, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal, pmena@fe.up.pt*

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Abstract:
A novel constricted meso-tube (4.4. mm internal diameter) operated with oscillatory flow mixing has recently demonstrated enhanced volumetric mass transfer coefficients (k_La) for continuous gas-liquid flows. Values of k_La up to 0.16 s^{-1} were obtained with a very low air-inflow rate (Q_G = 0.28 ml min^{-1}) for the continuous running of a liquid phase (Q_L = 1.58 ml min^{-1}), while in the presence of fluid oscillations. This is a one-order of magnitude improvement in the O_2 transfer efficiencies in comparison with those values typically found for the most common-aerated reactors (e.g. stirred tank reactor, bubbles column, air-lift reactor). The design of novel multiphase, scaled-down reactors based on this novel tube's geometry allows the intensification of gas-liquid flow processes through reducing the required processing volumes and the improved performance in terms of mixing, residence times and mass transfer. As a correct design does require a full understanding of the mass transfer processes, the different contributions of the mass transfer coefficient and the gas-liquid interfacial area in the global k_La enhancement were explored and herein reported.

Bubble sizes were measured with a fibre optic probe system in a 350-mm long meso-tube, vertically positioned and continuously operated with a gas-liquid flow. The fluid was oscillated at different frequencies (f = 0-20 s^{-1}) and centre-to-peak amplitudes (x_0 = 0-3 mm). A 1-mm reflectance probe was located perpendicularly to the flow direction at the tube-outlet and a 475 nm light beam was connected from a LED light source to the probe end. The emitted light was selectively reflected in a white background (6 mm pathway) back to the centre core of the fibre and fast-monitored with a spectroscope. The variation in the signal intensity of the reflected light (I) observed when the rising bubbles were crossing the beam allowed a fine estimation of the bubbles size (Fig. 1). More than 1,000 bubbles were sampled each measurement insuring that the effect of the sample size on the measured bubble chord length distribution is eliminated.

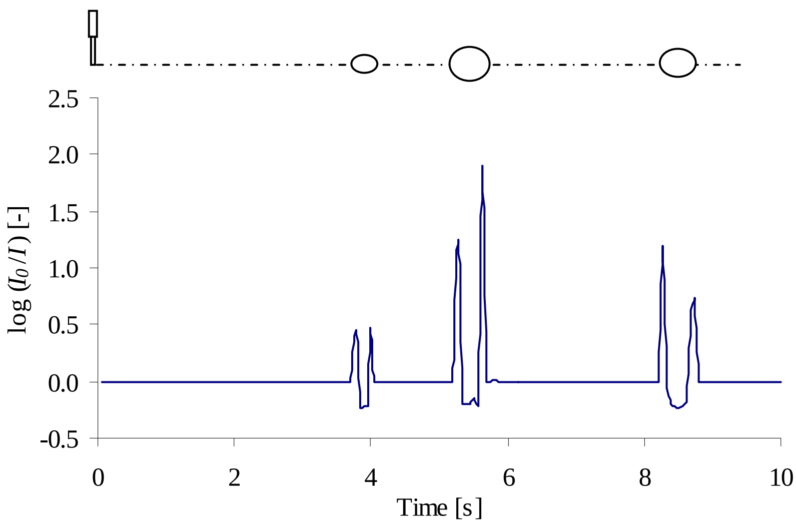

Fig. 1: Typical signals from the optical fibre probe.

Simultaneously, the optical bubble size's measurements were validated through the image analysis technique. Bubbles images were recorded with a CCD camera and afterwards post-processed with

Visilog (image analysis software), allowing the calculation of the equivalent circular bubble's diameter.

The full bubble size distributions were then generated by the bubble number fraction and used for the calculation of the mass transfer coefficient, k_L and the gas–liquid interfacial area, a from the volumetric mass transfer coefficient values previously reported (Reis et al., 2004a)

A bimodal distribution of bubble size was in general observed. The results demonstrate that bubbles' size in the meso-tube strongly depends on the oscillatory flow conditions (Fig. 2): the operation with smooth oscillations (say $f \leq 10$ s^{-1}) leads to a decrease of the bubble size, while for higher values of f (15-20 s^{-1}) the increased oscillatory velocities cause enhancing of bubble sizes.

Although significant variations of the interfacial area were observed in the tested range of f and x_0, the changing in bubbles size was found to play a marginal effect in the global enhancement of k_La in the meso-tube in comparison with the intensive reciprocating mixing experimented by the rising bubbles.

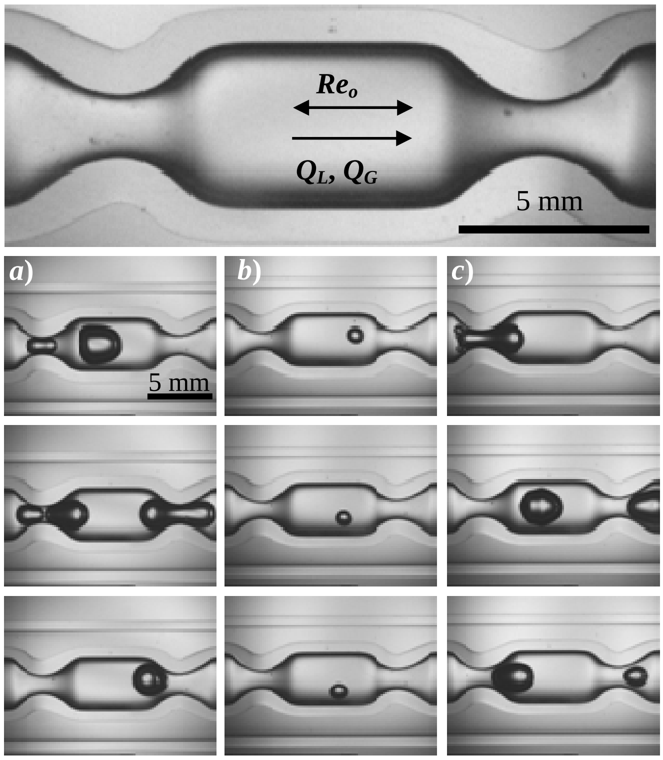

Fig. 2. Bubble sizes at increasing oscillation frequencies (f) and centre-to-peak amplitude (x_0): *a*) 1 mm and 3 s^{-1}; *b*) 2 mm and 10 s^{-1}; *c*) 3 mm and 20 s^{-1}. $Re_o = 2\pi f x_0 \rho d/\mu$; Q_L = 1.58 ml min^{-1}; Q_G = 0.28 ml min^{-1}.

The highly-controllable mixing and residence times previously registered for this meso-tube geometry (see e.g. Reis et al., 2004b) coupled with an improved gas-liquid contacting allows the running of numerous industrial gas-liquid flows processes through smaller and better.

References:

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