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Investigations of gas-liquid mass transfer around Taylor bubbles flowing in a long in-plane spiral-shaped milli-reactor

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A large number of investigations for gas-liquid mass transfer are performed in straight channels^[1], while the influence of the occurrence of bends along the channel (such as in meandering, spiral-shaped and helicoidal tube geometries)^[2, 3], still need to be deeply explored. They indeed enable to reach longer residence times with a more compact design while enhancing transport phenomena. Spiral-shaped milli-reactors, specially developed for flow photochemistry^[4, 5], offer a continuous curvature along the channel that can induce transverse Dean flows. However, no study reports investigations at a local scale on gas-liquid mass transfer in such devices. In keeping with this context, this work aims at locally quantifying the gas-liquid mass transfer in an in-plane spiral-shaped milli-reactor under Taylor flow conditions, and the effect of the tube curvature on this mass transfer. For that, the colorimetric technique proposed by Dietrich et al.^[6] was used.

The experimental set-up was depicted in Fig. 1(a). The spiral-shaped milli-reactor consisted of a tube (FEP material) inserted inside a channel carved into a flat transparent plate and wound according to an Archimedean spiral geometry. Air was used as gas phase. Liquid flow composed of glucose, sodium hydroxide and resazurin was supplied by a neMESYS syringe pump. The channel was lighted by a Phlox-LedW-BL LED backlight and the images were recorded by a ScMOS Pco.edge 5.5 camera. Two tubing configurations were considered according to their wounded positions on the plate: called ET (exterior tubing) and MT (medium tubing) configuration (Fig. 1 b), they were located from the 1st to 6th spiral circle and from the 7th to 15th spiral circle, respectively (almost 3 m in length). A self-written MATLAB program was dedicated to extract the hydrodynamic and mass transfer characteristics, such as: the bubble length and velocity, the liquid slug length, the evolution with the axial location in the channel of the bubble length and velocity and of the equivalent oxygen concentration inside the liquid slug.

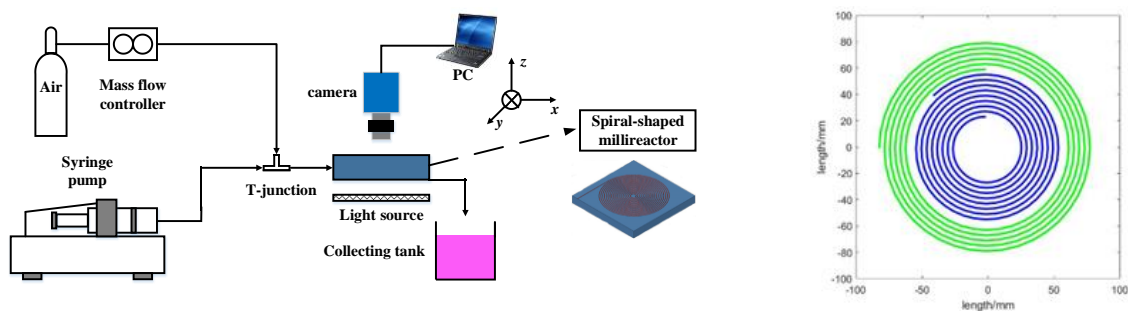


Figure 1: (a) Schematic diagram of the experimental set-up. (b) The tubing configuration, where green solid line: exterior tubing (ET); blue solid line: medium tubing (MT).

The operating conditions corresponded only to the Taylor flow regime. The typical flow map in the ET configuration is shown in Fig 2. Depending on the gas and liquid flow rates and on the tubing configuration, the mean Taylor bubble length and velocity were obtained and compared. The largest ratio of mean bubble length to tube inner diameter achieved was 27. As the experiments were carried out in long tubes, one observed significant changes of the bubble

volume and bubble velocity along the channel axial position. The latter increased linearly with axial position, while the liquid slug length almost contained constant. For a constant Re number, the accumulated oxygen mass was bigger in the MT than that in the ET, thus indicating that there was a significant enhancement of mass transfer due to the centrifugal force (Dean number). A first attempt of gas-liquid mass transfer model was proposed in an original way, which considered the variation of bubble volume and velocity along the tube length, due to the pressure drop.

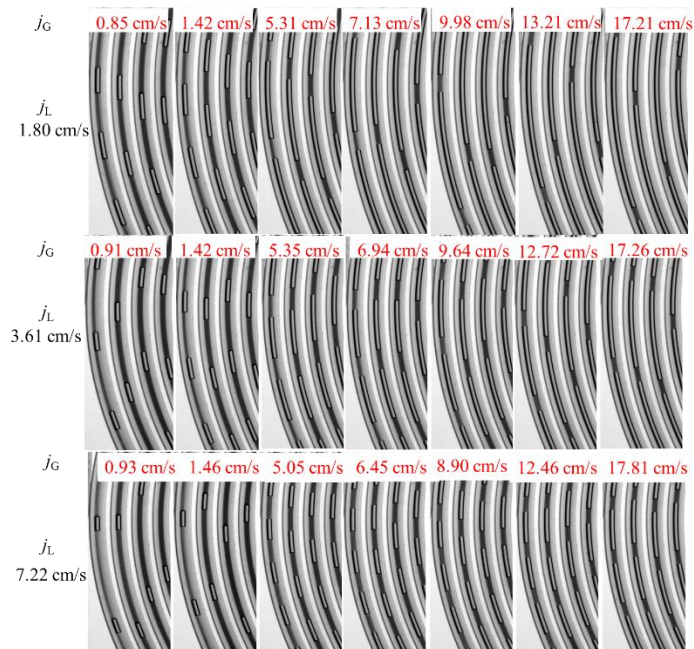


Figure 2: Cartography of gas-liquid flow in the configuration ET

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