Multi-scale analysis of gas-liquid flow in confined porous media

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1. Introduction

Multiphase flows in porous media are widely encountered in geophysical applications like new energy development (enhanced oil or gas hydrate recovery) [1], or natural processes such as gas venting [2, 3], but also in industrial chemical applications like catalytic reactors [4]. Consequently, a large variety of porous media and flow constraints exists. Usually, the underground porous medium can be modeled by spherical particles of different sizes, and in the specific field of heterogeneous reactors, classical fixed beds [5], or highly porous open cell solid foams [6] are encountered. In this study, we focus on the global and local hydrodynamic characterization of a gas-liquid co-current flow, constrained in a milli-channel, across two different porous structures: open cell solid foams and more classical packed beds of spherical particles.

2. Experimental device

The milli-channel consists in a horizontal straight channel of 22 cm long with a square cross-section of 2 mm width. It is made of PEEK (polyether ether ketone) and covered by a glass window permitting a direct visualization (Fig. 1a). The channel can be filled either by solid foam elements (Fig. 1b) for a total length of 16 cm or by micro-packed beds (Fig. 1c) for a total length of 15 cm. Different foams are tested : three NiCr metallic foams (2733, 3743 and 4753 from Recemat) and two vitreous carbon ones (80PPI, 100PPI from ERG aerospace) with a porosity in between $89 - 96\%$. Two micro-packed beds of polydisperse spherical glass particles have been employed, for which we vary the mean particle diameter and distribution ($75 - 150\mu$m, $180 - 300\mu$m). Their mean porosity is around 44%.

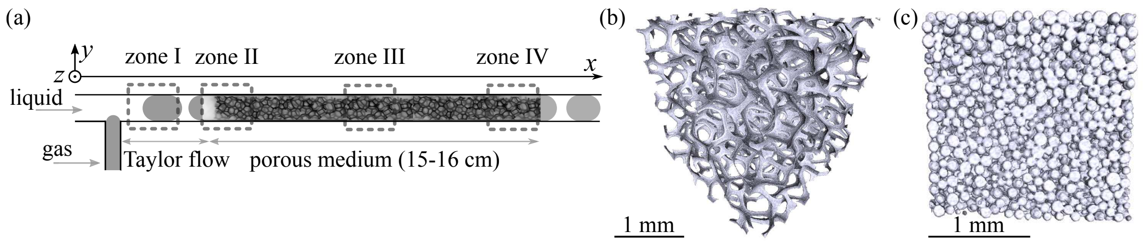

Figure 1: (a) Experimental device, top view of the milli-channel and location of the four visualizations zones used for the local hydrodynamics study. (b) Open cell solid foam and (c) granular medium XRay tomography images.

Gas (nitrogen) and liquid (ethanol) are fed co-currently in the form of a segmented flow. The velocity range of gas and liquid are: $8 < u_G < 146$ mm/s and $2 < u_L < 42$ mm/s . The liquid residence time distribution (RTD) is acquired by fluorescence microscopy and tracer pulse injections [7]. The pressure drop behavior is studied classically with differential pressure sensors. Local hydrodynamics and flow patterns are investigated through direct wall visualization (Fig. 1a) and image processing. For all these studies, a fluorescence microscope (Olympus BX51M) and a high speed camera (Solinocam H2D2, at 110 fps) are used.

3. Results and Discussion

Global hydrodynamics investigations have shown that the liquid flow rate and the porous structure are the key parameters controlling the residence time distribution shape (Fig. 2a). A discrete version of the Piston−Dispersion−Exchange (PDE) model with four parameters is proposed to describe the global liquid flow behavior [8]. The physical meaning of these parameters or their combination will be discussed. In order to complete global results and to participate in the understanding of the local hydrodynamics, the pressure drop has been investigated and a model based on the Darcy's law will be presented.

The local hydrodynamics consists on a spatio-temporal analysis of the film recorded at the wall. This leads to maps of an apparent phase repartition in the porous medium and to time-frequency and statistical studies of the variation of the liquid fraction inside the porous medium. The distance along the porous medium and the competition between inertial, viscous and capillary forces are predominant to describe the different hydrodynamic regimes. Fig. 2b illustrates the evolution of the main frequency (f_0) of the liquid fraction signal versus time, upstream (□) and at the entrance of the porous medium (•). Two regimes have been identified after a scaling analysis, depending on a modified Weber number We', corrected from the ratio of the monophasic Reynolds numbers Re_G/Re_L. The regime transition is characterized and could be predicted by a scaling model.

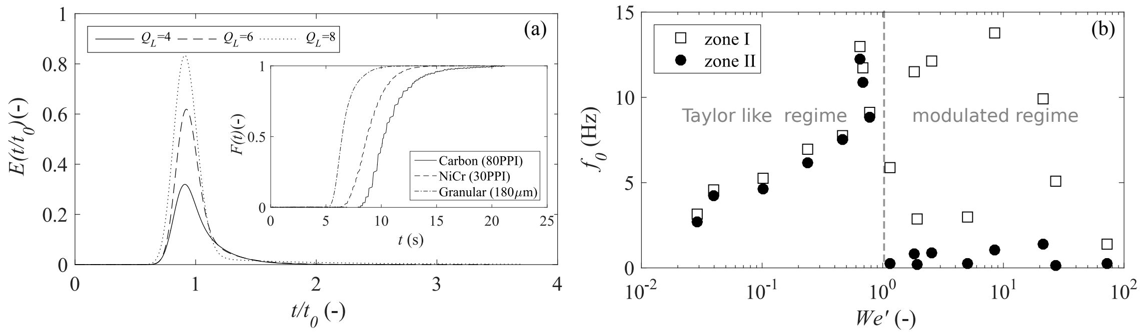

Figure 2: (a) Typical global hydrodynamics results. Modeling of the retention time distribution, $E(t/t_0)$, and effect of liquid flow rate (cm^3/min) on curve shape at a constant gas flow rate ($Q_G = 10$ cm^3/min). *Inset*: Experimental cumulative retention time distribution, F(t), for different porous medium structures. (b) Local hydrodynamics study, pulsed regime transition at the entrance of the porous medium. The signal main frequency, f_0, at the entrance of the porous medium, displays a clear regime transition as a function of a modified Weber number.

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