MULTI-SCALE ANALYSIS OF GAS-LIQUID FLOW IN POROUS MEDIA: EFFECTS OF CONFINEMENT AND POROUS STRUCTURE

Marion Serres[1,2], Valérie Vidal[1], and Régis Philippe[2*]
[1] Laboratoire de Physique, UMR 5672, CNRS – Ecole Normale Supérieure de Lyon,
Université de Lyon, 46 Allée d'Italie, 69007 Lyon, France.
[2] Laboratoire de Génie des Procédés Catalytiques, UMR 5285 CNRS – CPE Lyon,
Université de Lyon, 43 boulevard du 11 novembre 1918, 69100 Villeurbanne, France.

Abstract

A milli-channel and a plate reactor filled with various porous media (monolithic open cell solid foams or dense packed beds of polydisperse spheres) are studied under G-L flow conditions. Global (RTD and pressure drop) and local (direct wall visualization and frequency analysis) hydrodynamic studies are developed to analyze the effect of porous media properties on the multiphase flow occurring in these two bed structures. Experimental results and modelling will be exposed and discussed underlining the effect of a different confinement.

Keywords

Hydrodynamics, porous media, G-L flow, confinement, milli-channel reactor, plate reactor.

Introduction

Multiphase flow through porous media is commonly and widely encountered in geophysical processes like enhanced oil recovery or soil liquefaction, but also in industrial chemical applications like catalytic reactors. Consequently, a large variety of porous media and flow constraints exists. For example, in the specific field of heterogeneous reactors, classical fixed beds (Larachi et al., 1991), dense powdered micro packed beds (Marquez et al., 2008) or highly porous open cell solid foams (Stemmet et al., 2006) are encountered and studied under various flow and reactor configurations. In this study, we focus on the hydrodynamic characterization of a gas-liquid co-current flow across two different porous structures: open cell solid foams and more classical packed bed of spherical particles. Each kind of porous media is studied in two different set-ups in order to study some possible confinement effects: a milli-channel and a plate reactor.

Methodology

Milli-Channel

The reactor consists in a horizontal straight channel of 22 cm long with a square cross-section of 2 mm width. It is made of peek and covered by a glass window permitting a direct visualization (figure 1a). The channel can be filled for a total length of 16 cm either by foam elements or by micro-packed beds. Gas and liquid are fed co-currently in the form of a segmented flow. Liquid residence time distribution (RTD) is acquired by fluorescence microscopy and tracer pulse injections (like in Tourvieille et al., 2015). Pressure drop behavior is studied classically with differential pressure sensors (Honeywell bridge pressure sensor, response time: 1ms, pressure range: 5psi). Local hydrodynamics and flow patterns are investigated through direct wall visualization and image processing. For all these studies, a fluorescence microscope (Olympus BX51M) and a high speed camera (Solinocam H2D2, at 110 fps) are used.

Plate reactor

This reactor is used in order to liberate one degree of freedom for the multiphase flow. This set-up is commonly named a “Hele-Shaw cell” (figure 1b). Its characteristics dimensions are of 400x200x2 mm. It is made of two glass plates maintained together by a peek support and allowing the insertion of the same porous media than in the milli-channel. Nine gas injection ports permit to tune and control the bubble injection for a co-current upflow with the liquid. Liquid RTD is investigated with a conductimetric sensor still with tracer pulse injections. Pressure drop is acquired through differential pressure sensors and local

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[*] regis.philippe@lgpc.cpe.fr

hydrodynamics are studied through direct wall visualization and image analysis.

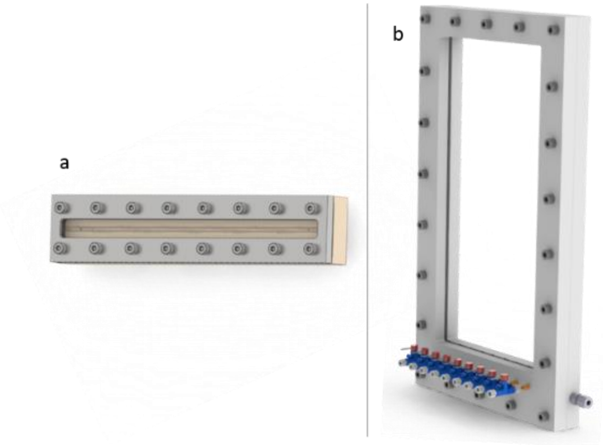

Figure 1: (a) milli-channel; (b) plate reactor

Porous media and fluids characteristics

Two micro-packed beds of polydisperse spherical glass particles (typical bed are shown in figure 2a) varying in mean particle diameter and distribution (75-150µm, 180-300µm) have been employed. Different foams are tested (typical foam structure is presented in figure 2b): three NiCr metallic foams (2733, 3743 and 4753 from Recemat) and two vitreous carbon ones (80PPI, 100PPI from ERG aerospace). Foam beds porosity lies in the range of 89-96% and packed beds in the range of 40-44%. Experiments have been conducted with nitrogen and ethanol or water-ethanol mixtures at ambient temperature and pressure (at the outlet). Gas and liquid superficial velocities were varied in the same range for both contactors: $8 < u_{G,s}$ (mm/s) < 146 and $2 < u_{L,s}$ (mm/s) < 42.

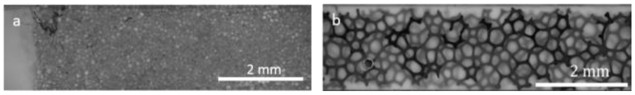

Figure 2: Typical porous media of the study

Results and discussion

Global hydrodynamics

Residence time distribution studies reveal that the liquid saturation and the dispersive behavior inside the bed depends mainly on the liquid flow rate (see figure 3a) and porous media properties (see figure 3b). A 4 parameters model (series of CSTR including a dead zone) gives a good estimation of the non symmetrical RTD curves (Sardin et al., 1991). The dispersive behavior and its physical representativeness will be discussed.

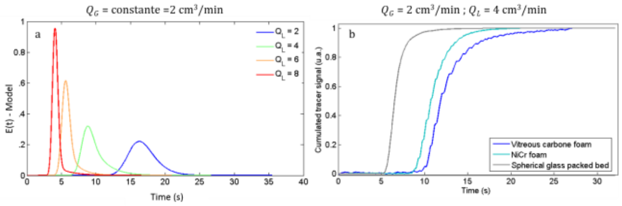

Figure 3: (a) RTD curves for a carbon foam;
(b) Outlet signals for different porous media

Local hydrodynamics

A spatial and temporal analysis of the film recorded at the wall permits to obtain qualitative maps of liquid presence probability along the reactor (a typical example is illustrated in figure 4). When pulsed flow is observed, a frequency analysis is performed. It allows to differentiate the various hydrodynamic regimes inside the beds and their evolution. For the milli-channel, the existence of two hydrodynamic regimes is observed and a criterion for the regime transition is proposed and discussed. Wall visualization experiments in the plate reactor and their analysis are in progress.

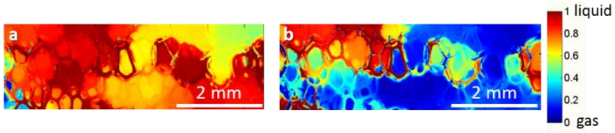

Figure 4: Mapping of liquid path probability,
a: good mixing; b: gas preferential paths

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