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## Bubble columns operated in the heterogeneous regime: towards a new understanding of their hydrodynamics

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Bubble column reactors, where gas is injected at the bottom of an initially stagnant liquid, are widely used in chemical engineering (e.g. for hydrogenation such as in Fischer-Tropsch synthetic fuels production), for bio-chemical transformations (aerobic bioreactors, algae production), waste management (wet oxidation) and flotation units (deinking of paper, extraction of rare metals). All these activities are also fundamental for the development of many recycling and renewable energies industries.

These reactors often operate in the heterogeneous regime, characterized by a strongly polydisperse distribution of bubble sizes, high gas concentrations (15 to 40%) and strong velocity fluctuations ( $\approx 25\text{-}30\%$  times the mean). Owing to such flow complexity, no reliable scaling rules are available for reactor designers (Kikukawa (2017), Besagni et al. (2018)). This problem dramatically hampers optimization and process control. In particular, extrapolation between laboratory-scale and industrial-sized columns (diameter 5 to 10 m, height 20 to 40 m) is not controlled, and therefore the simulations lead to realistic results only via an *ad-hoc* adjustment depending on the size of the column (Forret et al. (2006), Rollbusch et al. (2015)).

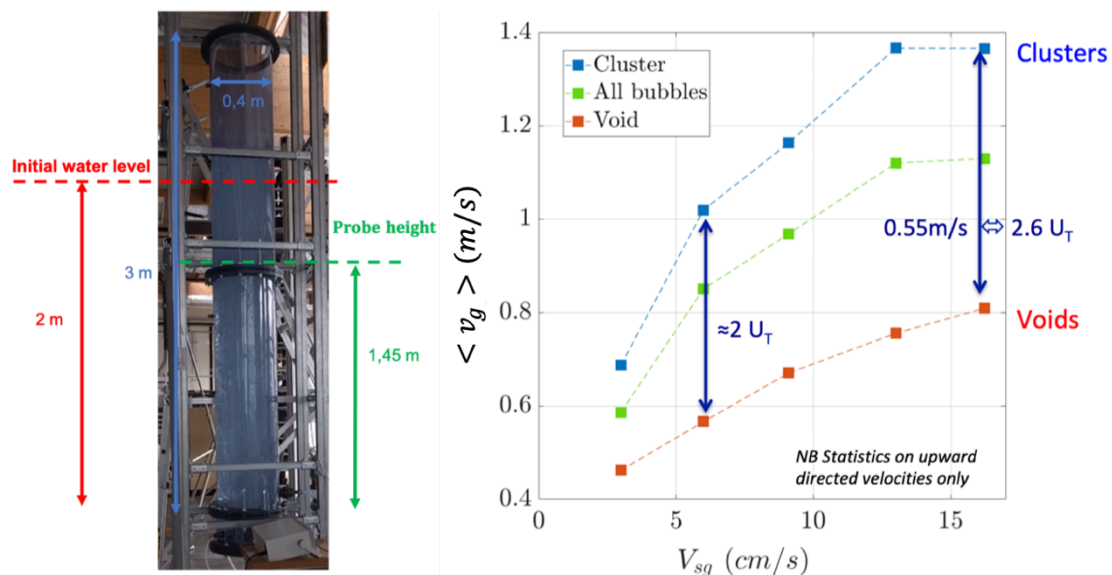


Figure 1: schema of the bubble column (left). Gas phase mean velocity for all bubbles and conditioned for bubbles within clusters and voids (right) as a function of  $v_{sg}$ .

In this work the hydrodynamics of bubble columns in the heterogeneous regime is revisited in the light of recent results. We present well-controlled experiments in a bubble column that is 3 meters high and has a diameter of 40 cm. It can reach superficial gas velocities ( $v_{sg}$ ) up to 25 cm/s that correspond to centreline void fractions of  $\varepsilon \sim 40\%$ . It has been designed in a way that coalescence between bubbles is small in the developed region of

the flow, but it can still reach the heterogeneous regime (see figure 1). Our results can be summarised as:

- 1) We first report results on a novel optical probe that can measure the size and velocity of bubbles via the Doppler effect of a reflected laser beam. It has the advantage that it does not depend on calibration for estimating the interface velocity. This probe produces gas residence time distributions and void fractions in good agreement with standard optical probes.
- 2) We also developed various methods to identify and characterize meso-scale structures. Concerning the dispersed phase, local void fractions become accessible from Voronoï tessellations built from optical probe signals. This technique allows to identify and characterise the clusters in terms of size and concentration and on their evolution with flow conditions. One of the main advantages of the new probe is that it allows to produce conditioned statistics even within the heterogeneous regime: we can indeed see that the bubbles velocities are strongly correlated to the local concentration and the presence of meso-scale structures (figure 1 right).
- 3) We finally propose a new scaling for both the liquid and gas velocities. By using a simple model that only balances the inertial terms with the buoyancy ones for the liquid phase, it is found that the liquid velocity scales at  $v_l \sim (gD\varepsilon)^{1/2}$ . As we can also access the fluctuating velocity (figure 2 left), we found that this scaling is also relevant for the mean and fluctuating gas velocities (figure 2 right).

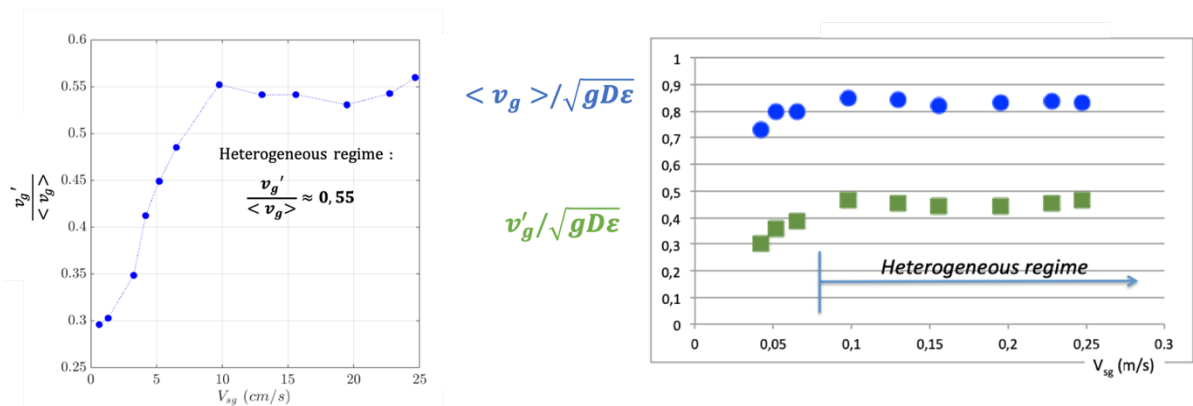


Figure 2: velocity fluctuations normalized with their mean values vs  $v_{sg}$  (left). Mean and fluctuating velocities of the gas phase as a function of  $v_{sg}$  (right).