CAMURE-11 11th International Symposium on Catalysis in Multiphase Reactors
ISMR-10 10th International Symposium on Multifunctional Reactors
MILANO, ITALY - 21-24 March, 2021

Bubbling fluidised bed reactors for strongly exothermic reactions – Gaining insight into hydrodynamic details to obtain better reactor models

Philipp Riechmann[1], Evert Wagner[2], J. Ruud van Ommen[2], Tilman J. Schildhauer[1*],
1 Paul Scherrer Institut, Research Division Energy and Environment, CH-5232 Villigen PSI, Switzerland
2 TU Delft, Dept. of Chemical Engineering (ChemE), Van der Maasweg 9, 2629 HZ Delft, the Netherlands
**Corresponding author E-Mail: Tilman.schildhauer@psi.ch*

1. Introduction

Conversion of chemical energy carriers often involves strongly exo- or endothermic chemical reactions such as methanation, Fischer Tropsch, gasification or hydrogenation/dehydrogenation of liquid organic hydrogen carriers. The challenge for these reactors is to ensure high conversion while not compromising the selectivity or, in many cases, the catalyst stability. Although technical solutions exist for large scale processes running continuously such as in the oil/gas industry, these cannot be directly transferred to an energy system that needs to integrate a large share of volatile renewable energy resources. Here, compact and flexible reactors at smaller scale are necessary.

Bubbling fluidised bed reactors allow for fast start-up and load changes, offer very high heat transfer rates to the immersed heat exchanger tubes even in part load, and have proven to be a robust and flexible technology for several investigated methanation processes. Models for these reactors often rely, however, on hydrodynamic correlations for reactors without heat exchangers and on simple assumptions with respect to the mass transfer inside the bed, e.g. that all bubbles at a specific height of the reactor have the same diameter. This work investigates in pilot scale the hydrodynamic details of bubbling fluidised reactors to advance rate-based models for this reactor type. With the improved rate based model of bubbling fluidised bed reactors, more realistic predictions of reactor performance, knowledge-based optimization and safer scale-up of such reactors will be possible in future.

2. Methods

Characterisation experiments for heat transfer and bubble properties (which limit the gas-solid mass transfer in bubbling fluidised bed reactors) are performed to improve a reactor model in several steps by introducing the bubble size distributions and the distribution of bubble rise velocity in different levels of detail:

- X-ray tomography experiments using a pilot scale flow model, and developing the statistical methods to derive information on global bubble properties from local information of pierced bubble chord lengths;
- Pilot scale (22 cm ∅) optical probe measurements to determine the distributions of bubble sizes and bubble rise velocities for 2-11 bar, several flow rates and two typical particles sizes (Geldart A and B);
- Flow model experiments in a Perspex model equipped with optical probes and a heat-flux sensor mounted on a heated tube to investigate the influence of bubbles on the local heat transfer;
- Pilot scale heat transfer measurements with different thermal conductivity (air, addition of H_2 or CO_2).

3. Results and discussion

In the Figure 1 below, pierced chord length results from cold flow experiments with optical sensors can be compared to the distribution of rise velocities and equivalent bubble diameters (diameter of a spherical bubble with same volume) which were obtained from X-ray tomography under similar operation conditions

[1]. It can be observed, that the results seem to be not completely consistent: X-ray tomography find fast low volume, but hardly fast large volume bubbles, while the optical probes indicate the presence of fast long, but hardly fast short bubbles. For large slow bubbles, it is inverted; they are found in X-Ray tomography, but optical probes do not show slow long bubbles.

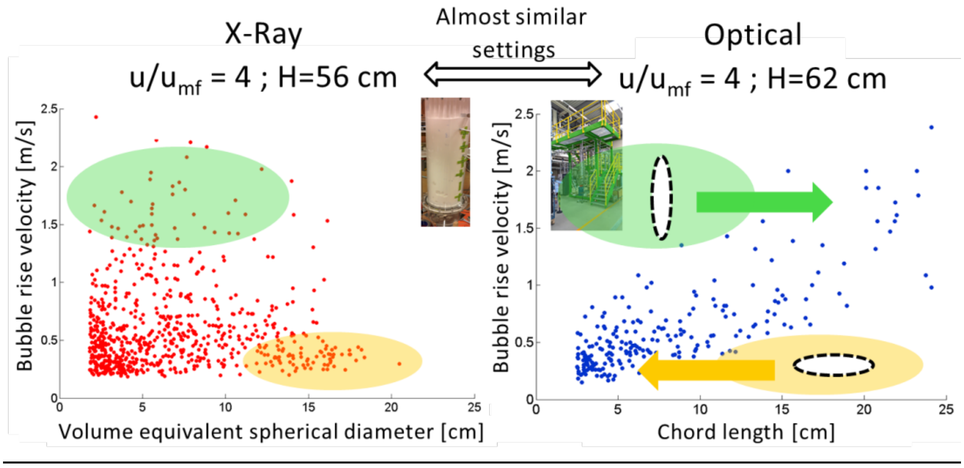

Figure 1. Comparing results from X-ray tomography (XRT, left) and optical probe measurements (right): bubble rise velocities of individual bubbles over their volume-equivalent spherical diameter (XRT, left) or pierced chord length (optical probes, right)

X-ray tomography data allowed investigating a potential correlation between the aspect ratio of a bubble and its rise velocity. As shown below in Fig. 2 for a freely bubbling bed without internals, the rise velocity of an individual bubble is clearly correlated with its aspect ratio, but less with its length. This opens a pathway to calculate the global bubble properties from local measurements which deliver the true rise velocity, but not the maximum bubble diameter. From the speed of a bubble, its aspect ratio can be determined to some extent, which together with the pierce probability of bubbles shapes allows derivation of its total volume.

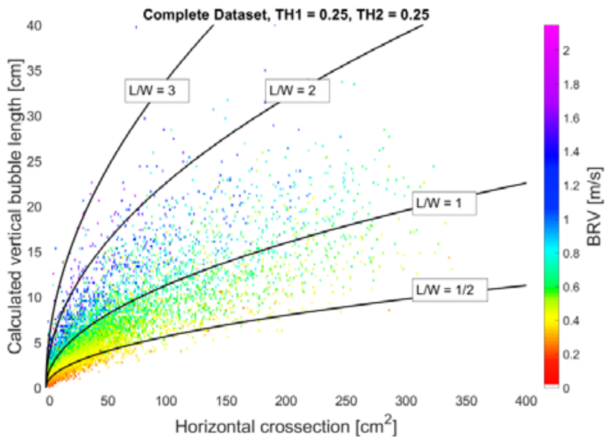

Figure 2. Lengths, aspect ratios and rise velocities of bubbles in a freely bubbling bed without internals (all measurement heights), obtained from X-ray tomography data

4. Conclusions

The methodological foundations for meaningful fluid-dynamic experiments in the pilot scale methanation reactor built at PSI are laid: the chosen diameter of the reactor with immersed heat exchanger tubes of real size is sufficiently large to obtain representative results for bubble properties and heat transfer measurements; and a thorough interpretation method of the (local) optical sensor measurements at different radial positions was developed (based on the observed correlation between aspect ratio of a bubble and its rise velocity) that allows conclusions with respect to the overall fluid-dynamic situation in the reactor.

References

[1] F. Schillinger, Dissertation ETH Zürich No. 25346, 2018