Optical investigation of bubble size and velocity in gas-liquid two-phase flow in complex structures using refractive index matching

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Long Abstract

Introduction

In chemical and pharmaceutical industry batch vessels are most widely used to conduct chemical reactions. Defined residence time and high selectivity are major advantages. Nevertheless, some disadvantages of batch reactors must be discussed and a new innovative and reliable technology must be found to ensure sustainability in the chemical and pharmaceutical industry in the near future. Therefore, porous structures are investigated for the use in continuous tubular reactors. They implicate good mixing, dispersion and heat transfer at a low pressure drop. Additionally, the increased surface to volume ratio ensures safe operation of exothermic reactions and provides a large surface as a potential catalyst support. For a better understanding of the fluid dynamics of a gas-liquid two-phase flow in porous structures, the bubble size evolution and velocity as well as the liquid flow field must be studied. The specific interfacial area between the gas and liquid phase is a critical value for the estimation of the gas-liquid mass transport in chemical reactions and the path the bubbles travel give indication on the break-up mechanisms. Particle image velocimetry is applied to measure the liquid flow field around the gas-bubbles. Calculating the turbulent kinetic energy and turbulent dissipation, the k-epsilon model can be applied to determine the turbulent diffusivity.

1. Methods

The key to optical investigations of flows inside porous structures is the index matching of the fluid and the structure material. Somos® WaterShed XC 11122 is used as structure material and an aqueous solution of sodium iodide and zinc iodide provides optical access to the structure [4].

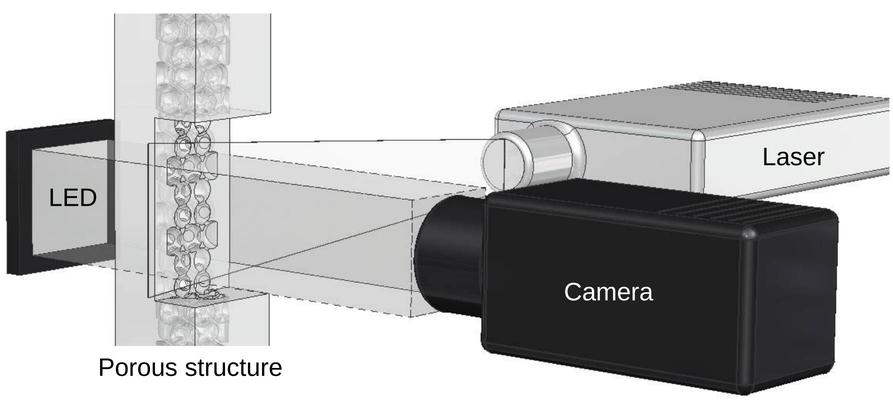

Figure 1. Setup

Planar shadow imaging (PSI), a proven technique in bubble columns [3], is used for bubble detection within the investigated porous structure. The liquid-flow field is investigated using planar particle image velocimetry (PPIV). Laser, camera and background illumination are arranged around the porous structure as presented in Figure 1.

The acquired images show overlapping shadows of bubbles, as the bubbles are travelling in different layers through the structure. To allow size measurements of these overlapping shadows, ellipses are fitted along the bubble contours, see Figure 2a [1,5]. In a next step, the velocity is determined from consecutive images acquired by high speed imaging at 1000 frames per second, see Figure 2b. The concept of the pseudo-distance is adapted to match the bubble shadows between the images and to allow overlapping shadows to be tracked [2,6]. In a last step, PSI and PPIV are combined and the liquid flow field is studied, see Figure 2c. A notch filter is mounted on the camera to remove any laser light reflections coming from the bubble surfaces, for that reason fluorescent tracer particles are used.

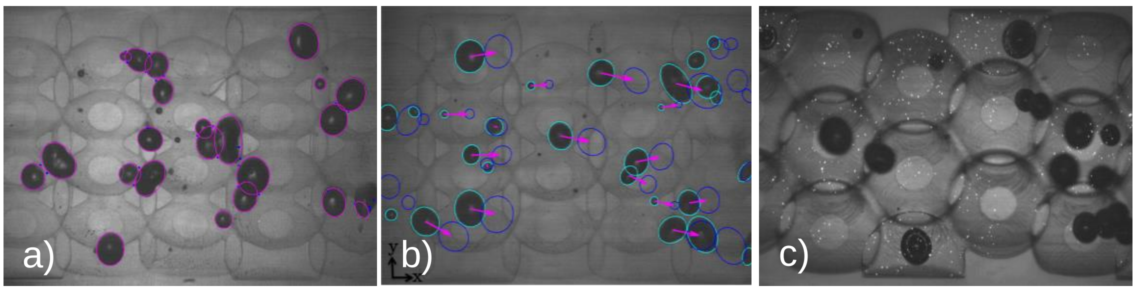

Figure 2. a) Bubble detection by ellipse fitting b) Bubble tracking c) PSI and PPIV

2. Results

It is shown, that the bubbles are well broken-up inside the porous structure. The optimal operation point to increase the specific interfacial area between the liquid and the gas phase is found at a Reynolds number of 200 and a volumetric transport fraction of 2.1%. Higher flow rates are not increasing the specific surface any more, but only wasting pumping energy [1]. The influence of the frame rate on the bubble tracking capability is studied and 1000 frames per second are found to be sufficient. Measurements of the bubble velocity show that the buoyancy force is reduced inside the structure due to bubble-wall interactions. This bubble-wall interaction can also be seen as the major mechanism for bubble break-up [2]. Based on planar particle image velocimetry measurements, the energy dissipation rate is determined and compared with results obtained from pressure drop measurements.

References

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