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On the hydrodynamics of airlift reactors, Part I: Experiments

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HIGHLIGHTS

- CFD-grade data for model validation.
- Locally resolved measurements in the riser and downcomer.
- Reynolds stresses determined with micro-bubbles.
- Transient behavior of airlift reactors.

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ABSTRACT

It is more and more possible to design bubbly flow reactors with methods of the computational fluid dynamics (CFD). Measurements that can be used for model validation, however, are often missing, especially for complex setups like airlift reactors. Such measurements include locally resolved information about the dispersed and continuous phase, particularly the information about the flow field and interface structures are important. In the present work Reynolds stresses, liquid velocity and gas void fraction profiles as well as bubble size distributions are provided at several positions in the riser and the downcomer in a rectangular airlift reactor for this purpose. In addition, the hydrodynamics inside this airlift reactor are described in detail by the measured values.

1. Introduction

Multiphase reactors are used in a wide range of industrial applications. For example, the momentum, heat and mass transport in a fluid is intensified by aerating. As a result, complex flow phenomena arise in simple reactor geometries, from which a bubble column might be the simplest form. Here, the gas bubbles drive the flow and the liquid is rising in the center and falling near the wall in general. The up- and downward flow are next to each other and can interact. Alternatively, internal walls can be placed in bubble columns to separate the up and downward flow; these reactors are called internal airlift reactors.

For many applications that use airlift reactors it is important to know the exact fluid dynamics. For example, the light exposure of microorganisms in airlift photo bioreactors can be optimized by knowing the fluid dynamics (Fernandes, et al., 2010). Moreover, the shear rate and turbulence parameters are important for all process with microorganisms (Liu and Tay, 2002) (Miron, et al., 2000) (Oliver-Salvador, et al., 2013) and for mass transfer modeling (Korpijarvi, et al., 1999) (Lu, et al., 2000). Nevertheless, such detailed information of the fluid dynamics is rarely accessible by the use of experiments.

A better understanding of the underlying fluid dynamics is gained by using the methods of the computational fluid dynamics (CFD). The Eulerian two-fluid approach is a widely used approach (Ziegenhein, et al., 2015) (Luo and Al-Dahhan, 2011) to model the dispersed multiphase flows that occur in airlift reactors. Using the two fluid model, the multiphase problem is described by phase averaged equations. As a result, the interactions between the dispersed phase and the liquid phase have to be modeled by closure models (Ishii and Hibiki, 2006). Those closure models exist in a large variety; they are often selected to a specific problem dependent on the agreement with an experiment, which is in the end a fitting. However, a reliable set of closure models is necessary to predict unknown setups. Therefore, an extensive model validation is required (Lucas, et al., 2016).

For such a model validation, comprehensive experimental data are needed. Such data have to provide locally resolved flow parameters since all effects in bubbly flows are strongly connected to each other. Moreover, the data should include the gas volume fraction, the liquid velocity, basic turbulence parameters and the

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bubble size distribution. In particular, the bubble size distribution is of importance because all closure models depend on the bubble size.

A lot of work was done simulating airlift reactors in the past with the Eulerian two-fluid approach. However, in general the bubble sizes were not known (Huang, et al., 2010) or only known in the downcomer (Luo and Al-Dahhan, 2011). Moreover, often only integral measured values were available (Simcik, 2011) (Ghasemi and Hosseini, 2012). Hence, a validation of the closure models in airlift reactors is limited with the existing experimental data.

The motivation of the present work is to provide a comprehensive set of locally measured data in an internal airlift reactor for the validation of CFD methods. To the best of our knowledge, those measurements were not published in the past and are urgently needed. Moreover, the measured data provide a complete picture of the flow in an internal airlift reactor.

2. Experimental setup

The used rectangular Plexiglas® bubble column with internals is shown in Fig. 1. The cross section of the airlift reactor is 0.25×0.05 m. The 5 mm thick internal walls separate the 0.12 m wide riser from the downcomers. Each downcomer has a width of 0.06 m so that the riser and the sum of both downcomers have the same cross section. The distance from the ground plate to the beginning of the internal walls is 0.06 m, which is equal to the width of a downcomer. In addition, the distance from the top of the internal walls to the water surface (the top clearance) is held constant to 0.06 m for all gas volume flows. Thus, the liquid level is at 0.72 m above the ground plate for all setups.

Liquid velocity, turbulent kinetic energy, available Reynolds stress tensor components and bubble sizes are determined at a height of 0.2 m and 0.6 m in the riser and the downcomer, which

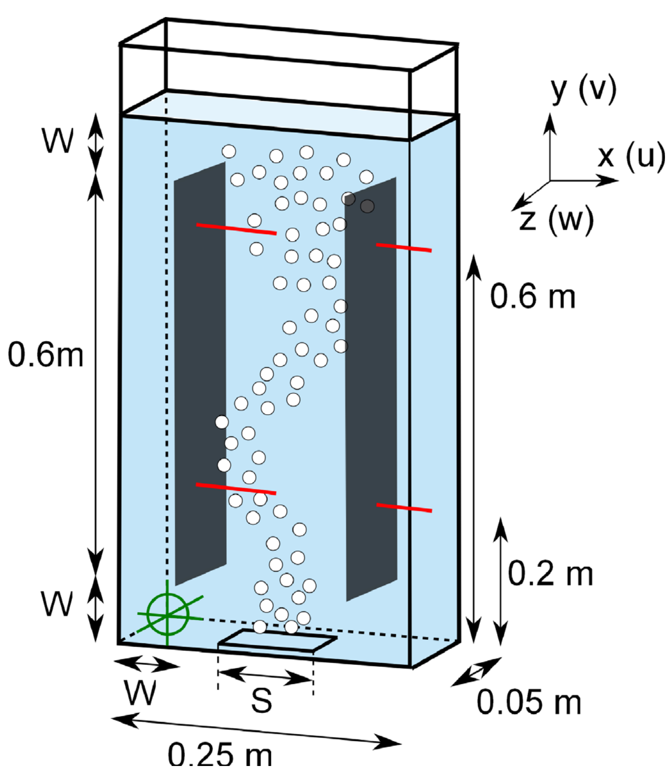

Fig. 1. Experimental setup, lines label the measuring positions. The origin of coordinates is in the bottom left corner.

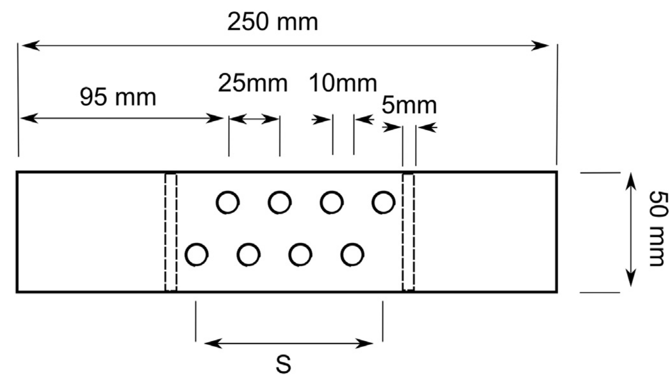

Fig. 2. Ground plate of the airlift reactor.

is indicated with red lines in Fig. 1. The void fraction is measured at a height of 0.6 m in the riser. In addition, the bubble size distribution and the void fraction are determined along the downcomer.

Rubber seals that are attached at the side of the internal walls hold them in place. Therefore, no interaction between the riser and the downcomer is possible and no flow disturbing installations are needed to hold them in place. The gas is injected through the ground plate, which is shown in Fig. 2, by using up to eight needles with an inner diameter of 0.6 mm. The volume flow per needle is held constant for all cases to get a similar bubble size distribution. The total gas volume flow is regulated by changing the needle count. A summary of the important parameters is given in Table 1.

3. Measuring methods

The bubble size distribution is determined with videography at several positions, which is discussed in Section 3.1. The volume fraction in the riser is measured with a conductivity needle probe. In contrast, the volume fraction in the downcomer is determined with videography. Both methods are discussed in Section 3.2. The liquid velocity and the turbulent kinetic energy are measured with particle-tracking velocimetry using micro bubbles (BTV), which is discussed in Section 3.3. All image processing is based on own developed programs.

3.1. Bubble size distribution

The bubble sizes are determined by using digital image analysis. Despite a certain amount of automation, e.g. as discussed by Broeder and Sommerfeld (2007), bubble sizes have to be identified by hand in complex flow situations, which occur in the riser for all cases as illustrated in Fig. 3. Edge detecting algorithms are used to speed up the manual bubble identification, so a large amount of bubbles can be tracked. Nevertheless, as bubble clusters occur in all complex flows, bubbles are overlaid by other bubbles, which lead to problems. The structure of the cluster, however, is changing

Table 1
Experimental parameters at standard conditions.

Case number	Volume flow (l/min)	Sparger needle (mm)	Needle count	Volume flow per needle (l/min)	*S* (mm)	*W* (gas on) (mm)
4	3	0.6	4	0.75	35	60
6	4.5	0.6	6	0.75	60	60
8	6	0.6	8	0.75	85	60