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Estimation of velocity fields from the axial wire-mesh sensor data

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ABSTRACT

Various Wire-Mesh Sensor (WMS) designs have been developed and applied for the single- and two-phase flow studies over the recent years. The design and the construction of the WMS can significantly vary depending on the purpose of the research. Typically, the WMSs installed in pipes and ducts have been located across the flow, to obtain instantaneous cross-sections of the flow area. The traditional approach would not be ideal if the scope of the study is to measure the development or the dynamics of the flow in the axial direction. Hence, the axially-aligned conductivity Wire-Mesh Sensor (named AXE) was designed and constructed to be located in the centerline of the 50 mm pipe in the current study.

The paper presents briefly the design of the axial sensor and the HIPE test loop that was used in the experiments. The sensor enables the study of the two-phase flow in high resolution (10,000 frames/s, 3 mm $\times$ 3 mm resolution). In this paper, the main emphasis is on the study of the different methods that can be applied for the estimation of the velocity fields from the axial wire-mesh sensor data. Two methods have been tested: traditional Time-of-Flight (ToF) estimation and optical flow method. The Time-of-Flight estimation relies on the cross-correlation of the time series of the void fraction values from the different locations. The velocities can be calculated from the Time-of-Flight estimates and the distances between the particular locations. The optical flow methods can be used to evaluate the motion of the objects between the two sequential images. The estimation of the velocity fields from the axial sensor data is analogous to the calculation of the velocity fields from the Particle Image Velocimetry (PIV) images. Now, the same methods are applied to process the axial WMS data. The paper discusses the pros and cons of the different approaches and gives some general recommendations on how and when they should be applied for the WMS data. The velocity fields from the axial sensor experiments are compared to the experiments conducted with the two cross-sectional WMS (32 $\times$ 32 sensors). One aim of the studies on axial sensor is to utilize the sensor in research dealing with swirling flows generated by different mechanisms.

1. Introduction

The movement, the interaction processes and the size of the interfacial structures have been in the focus of the flow research for ages. The deeper understanding of how and why the two-phase flow structures behave as they do has motivated the researchers to develop various advanced flow sensors and measurement techniques. Dual/multiple-tip resistivity, conductance and optical needle probes have been widely applied to measure the void fraction and interfacial velocities (Kocamustafaogullari and Wang, 1991; Revankar and Ishii, 1992; Lucas et al., 2004; Xue et al., 2008). In the late 90s, the Wire-Mesh Sensor (WMS) technique was developed to offer new possibilities in the flow studies (Prasser et al., 1998). The grid sensor measures the conductivity/capacitance of the mixture connecting each cross-point of the sensor in high temporal and spatial resolution. The performance and the intrusiveness of the sensor have been examined in several studies (Manera et al., 2009; Wangjiraniran et al., 2003; Beyer et al., 2010; Ito et al., 2011; Nuryadin et al., 2015).

The greatest advantage of the WMS is that it doesn't have to be traversed to measure the whole flow area as it is necessary with the needle sensors. The three dimensionality of the data enables the detection of the flow interfaces and the detailed analysis of the flow behavior. Here, the third dimension in the data is time. The high resolution data is valuable in the development and the validation of modern CFD codes. The wire-mesh sensor enables the gathering of flow data from the two-phase flows with high bubble densities that are inaccessible with the optical methods such as high-speed cameras.

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2. Experimental set-up

The brief overview of the test facility and the sensor used for the measurements is provided in the following sub-sections. The first results obtained with the axial WMS, its design and construction were presented in the previous conference paper by the authors (Ylönen and Hyvärinen, 2015).

2.1. The HIPE test facility

The adiabatic test loop (HIPE) was constructed to study various two-phase flows in an inclined pipe. The test facility is also used for the educational purposes as the transparency of the flow channel allows the students to observe the different two-phase flow phenomena. The facility has a transparent test section, whose alignment can be arbitrarily changed between the vertical and the

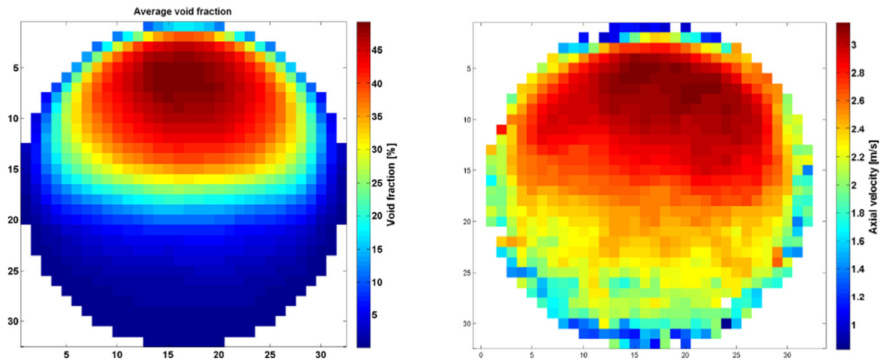

Fig. 1. Time-averaged void fraction distribution (left) and time-averaged axial velocities (right), J_L = 1.2 m/s and J_G = 0.6 m/s, 45°.

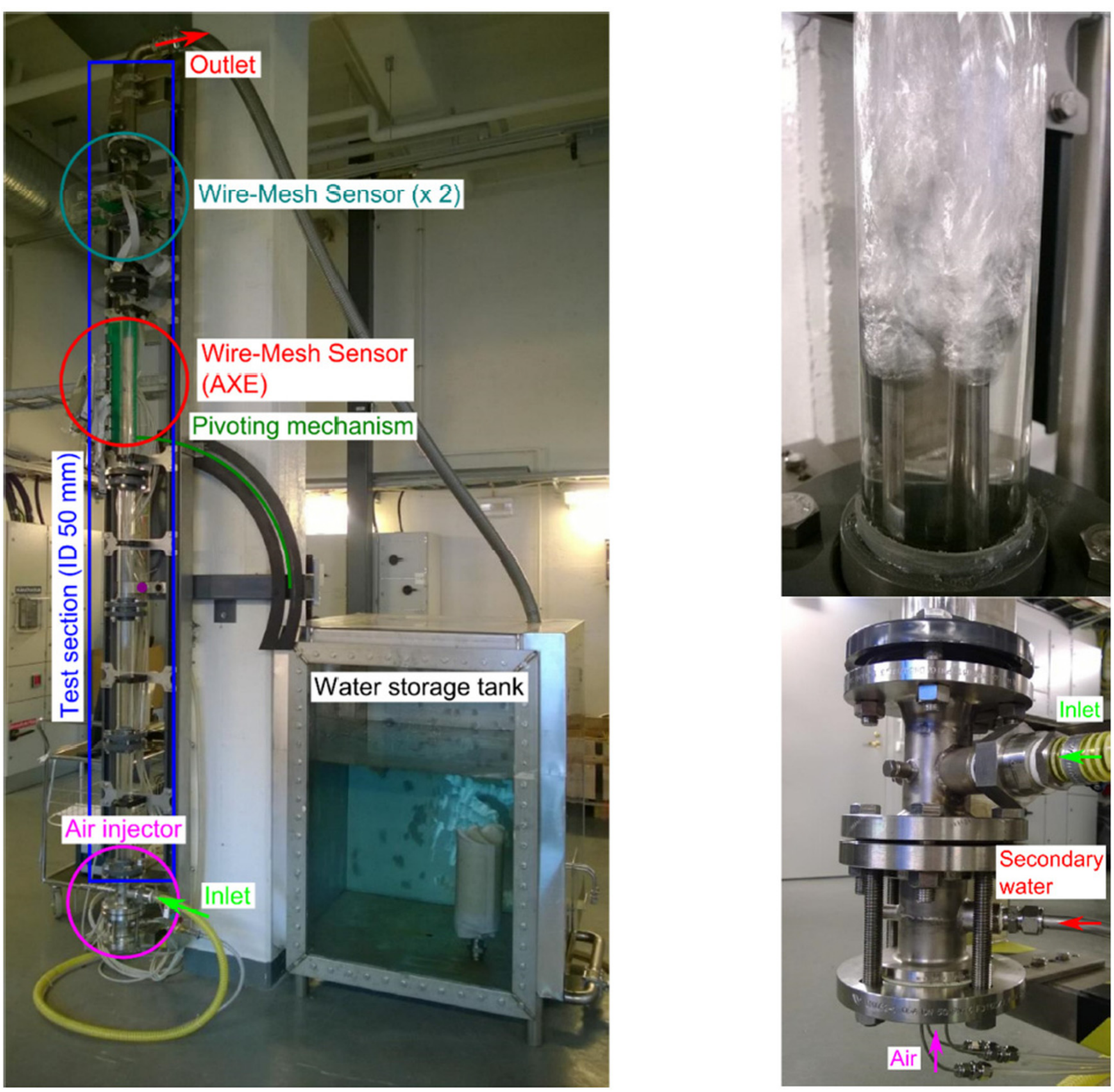

Fig. 2. The HIPE test facility (left), the detailed view of the air injector (right, bottom) and the air bubbles departing from the injector pipes (right, top).

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