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On the accuracy of wire-mesh sensors in dependence of bubble sizes and liquid flow rates

S. Nuryadin [a], M. Ignaczak [b], D. Lucas [b], Deendarlianto [a,c,*]

[a] Department of Mechanical and Industrial Engineering, Gadjah Mada University, Jln. Grafika No. 2, Kampus UGM, Yogyakarta 55281, Indonesia
[b] Helmholtz-Zentrum Dresden-Rosendorf (HZDR), Institute of Fluid Dynamics, P.O. Box 510119, 01314 Dresden, Germany
[c] Center for Energy Studies, Gadjah Mada University, Sekip K-1A Kampus UGM, Yogyakarta 55281, Indonesia

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ABSTRACT

An experimental study to assess the accuracy of wire-mesh sensors in dependence of bubble sizes and flow rates has been performed in a 50 mm × 50 mm transparent rectangular channel. The liquid superficial velocities were ranging from 0 m/s up to 0.62 m/s with the obtained bubble size ranging from 3 mm to 7 mm. A single wire-mesh sensor with 16 × 16 electrode wires was used with a temporal and spatial resolution of 10 kHz and 3.1 mm (lateral distance between two wires), respectively. Single bubbles with known bubble size, subsequently called reference bubble size, was injected into the test section via bubble injector approx. 25 cm upstream of the wire-mesh sensor. The bubble size measurement by using wire-mesh sensor cannot be obtained directly since it requires the information of bubble velocity which is not available only by installing a single sensor. Therefore, a stereoscopic observation was conducted to obtain the bubble velocity by tracking the successive frames as well as to study the intrusiveness of the sensor. This configuration gave an advantage that the registered bubble will be assigned with its real approach velocity and a better agreement is expected. As the result, a direct comparison of all individual bubbles with the reference bubble size showed an agreement within ±10%. However, a deceleration effect was found for low superficial and observed to disappear as the liquid superficial velocity increased then vanish at observed $J_L = 0.62$ m/s.

1. Introduction

Wire-mesh sensors have been applied extensively to various cases of two phase flow phenomena. Several investigations have shown the capability of these sensors to provide valuable data for different gas–liquid two-phase flows. Example are: bubble size and local gas volume fraction distribution in a rectangular bubble column by Krepper et al. [4], data on the evolution of co-current air–water two phase flows by Lucas et al. [2], experimental investigations of horizontal slug flows by Da Silva et al. [10], and others. The data obtained by such measurements have been used extensively for CFD code development and validation.

The wire-mesh sensor consists of two parallel layers of wires which cross under an angle of 90°, but which do not touch. The electrical conductivity of two-phase mixture is measured at all the crossing points of two layers of wires within the sensor, as it was described in Prasser et al. [5–7]. As a result, the cross sectional averaged void fraction for each time-step as well as the overall void fraction can be obtained and visualized. In case of an air–water system, air is considered to be electrically insulating while pure water is a conducting fluid with a value of about 10μS/m. However, this method is classified as the intrusive measurement method since the presence of wires which are stretched over the measurement section disturbs the flow. Therefore, a study related to the intrusiveness as well as the accuracy of this method should be performed.

The intrusive effects appear in form of bubble fragmentation [7] and bubble deceleration when it touches the wires [1,7,14]. As reported by Wangjiraniran et al. [14], the deceleration due to the presence of wire was observed to reach 40–50% in case of liquid superficial velocity lower than 0.2 m/s. This was confirmed by the result from Ito et al. [1]. The bubble velocity was then recovered after 4δ–8δ downstream of the sensor ($\delta = 2$ mm, is the axial distance between two wires). The deceleration effect disappeared at $J_L = 0.6$ m/s and as J_L increased up to 0.8 m/s, a slight acceleration within axial distance between two wires was observed as can be seen in [1]. It can be explained by the obstruction of the flow area

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* Corresponding author at: Department of Mechanical and Industrial Engineering, Faculty of Engineering, Gadjah Mada University, Jln. Grafika No. 2, Kampus UGM, Yogyakarta 55281, Indonesia. Tel./fax: +62 274 521673.

E-mail address: deendarlianto@ugm.ac.id (Deendarlianto).

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which increases the liquid velocity. Because of this the bubble is transported faster.

The accuracy of the wire-mesh sensor related to the void fraction profile was examined by comparing the obtained result with a reference measurement method. A comparison with X-ray tomography data from Prasser et al. [8] showed a deviation of 1% for bubbly flow while an underestimation up to 4% was observed for slug flow. This underestimation yielded from the falling film formation in the wake region of the electrode wires. A similar result for radial gas fraction can be seen in Zhang et al. [15]. A comparison with gamma densitometry [7] showed that the deviation between these methods was limited to ±5%. In Sharaf et al. [13], both conductance and capacitance WMS's void measurement results were compared with gamma densitometry. They reported that the agreement was in range of ±10% at the pipe center region. However, there was a significant difference as it close to the wall or at the edges of the pipe due to an inherent limitation of the devices in this region. On the basis of equivalent bubble size, Scholz et al. [3], an overestimation up to 50% and 20% was found at low and high liquid superficial velocity, respectively, while the result from Ito et al. [1] showed a scattering result within ±20% both for low and high liquid superficial velocities.

The measurement error appears as a result of the intrusive effect due to the presence of wires, applied assumption for bubble size calculation, and the error contribution from the reference bubble size. Therefore, a further study is still needed to have a deep understanding in how interaction between single bubble and WMS affects the measurement accuracy. In addition, the effect of reference bubble has to be considered since the reference method has an error too. The present research is aimed to determine the systematic error of the wire-mesh sensor by introducing single bubbles of well-known size under variation of liquid superficial velocity ranging from $J_L = 0$ m/s up to $J_L = 0.62$ m/s. In the present research, a simultaneous measurement between wire-mesh sensor and high-speed camera observation was carried out. The improvements from the previous studies [1,3] have been achieved by two major advances. First a stereoscopic observation was performed what leads to a higher precision in the determination of the velocity. As mentioned in Nedderman [12], all three coordinate positions, i.e. x, y, z can be derived by stereoscopic photography method. Nedderman [12] measured the position of moving bubble in known interval time and further will give a velocity profile. Second instead of using the image taken from the optical observation (HSC), which may cause a lack of accuracy as J_L increase, the reference bubble size was calculated in a separated system. For the WMS data, the bubble size was still in virtual size since the use of a single sensor cannot provide the bubble velocity information which is necessary for bubble size calculation. Hence, the virtual bubble size from the WMS data is multiplied with the bubble velocity from optical observation to obtain the real bubble size. Further, the accuracy is checked by direct comparison of the wire-mesh sensor calculation with the reference bubble size.

2. Wire-mesh sensor

In principle, the wire-mesh sensor measures the instantaneous electrical conductivity of the two phase mixture at the crossing points between the two layers of wires which are installed in two different axial positions. In case of an air–water system, air is considered to be electrically insulating while pure water is a conducting fluid. The wire-mesh sensor construction is based on a matrix arrangement of electrode wires that represents the measuring points. These electrode wires are spanned in two different axial positions which form two layers of mesh/grid wires. The first layer is a current transmitter while the other ones is a current receiver. According to Prasser [6], the transmitter wires are activated by a multiplex circuit successively. When one of the switches (see Fig. 1) is connected then the receiver wires scan the received current individually. In such way, the current flows to the receiver wire through a control volume of a two-phase mixture around the crossing point of two wires. The currents are converted into voltages by operational amplifiers and sampled by individual sample/hold circuits. Then, the analogue/digital conversion signals are stored for each receiver wires. These procedures are repeated for all transmitter wires. After the activation of the last transmitter, a two-dimensional matrix containing the conductivity values of all crossing point is obtained. The local void fraction is calculated by an assumption of proportionality between electrical conductivity and void fraction, as follows:

$$\alpha = \frac{U_W - U_{meas}}{U_W} = 1 - \frac{U_{meas}}{U_W} \tag{1}$$

where α is the local void fraction, U_W is the sensor signal of the calibration value (water), and U_{meas} is the sensor signal of the measured value. For the present test, a wire-mesh sensor with 16×16 electrode wires was installed in a $50\,\text{mm} \times 50\,\text{mm}$ rectangular transparent channel. By this configuration, a simultaneous test between wire-mesh sensor and high-speed camera observation

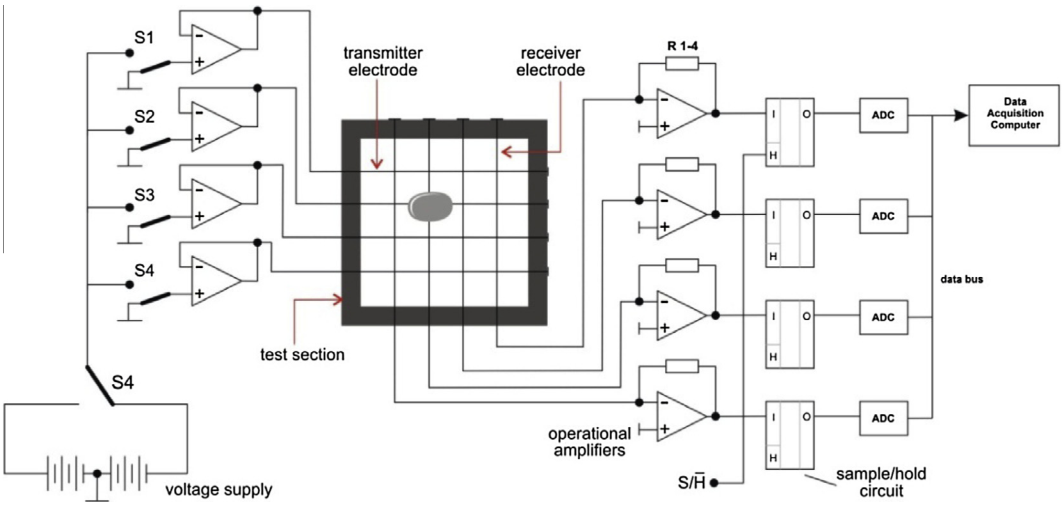

Fig. 1. Simplified electrical scheme for example of 4 × 4 wire mesh sensor.