The effect of liquid viscosity on the void friction in a two-phase gas-liquid flow in narrow mini-channels
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# The effect of liquid viscosity on the void friction in a two-phase gas-liquid flow in narrow mini-channels

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## Abstract

Investigations of the void fractions in the two-phase liquid–gas flow with liquids of viscosities differing from water viscosity are presented in the paper. In experiments two channels 15 mm wide and with different slit sizes 1.23 mm and 2.31 mm were used. Liquid phase was water and aqueous saccharose solutions. The fraction of gas phase was determined on the basis of an image of two-phase mixture flowing in the channel, recorded by a quick DDC camera. From the experiments it followed that liquid viscosity had a significant effect on phase fractions in the flowing two-phase mixture. The experimental data were correlated using a drift flux model.

Key words: void fraction, two-phase flow, mini channel, narrow channel, viscosity.

## 1. Introduction

Flows of two-phase mixtures in mini- and microchannels have become recently a subject of extensive studies. This interest in two-phase liquid-gas flow in a confined space is evoked by a possibility of intensifying heat and mass transfer processes as well as selectivity and miniaturization of the processes. Two-phase flow in mini- and microchannels finds applications in heat microexchangers, space technology, cooling of microelectronic devices and nuclear reactors. It is also used in bioengineering and biotechnology as well as in environmental engineering. Additionally, it is applied in the description of geophysical processes, e.g. extraction of geothermal water or petroleum (Dziubiński, 2005).
In narrow mini-channels important differences can be observed in two-phase flow hydrodynamics as compared to bigger ducts (Ide et al., 2005 and English et al., 2005). This refers first of all to flow structures, phase fractions and flow resistance. Studies published so far have referred mainly to the description of flow hydrodynamics of two-phase water-air mixture (Ide et al., 2007). There are no works dedicated to the flow of two-phase mixtures with liquids of higher viscosities than viscosity of water.

The aim of experiments was to investigated the effect of liquid viscosity on void fractions in the two-phase liquid-gas flow in narrow mini-channels and to compare the obtained results with relations available in the literature.

## 2. Experimental set-up and methods of measurements

Figure 1 shows a schematic of the experimental set-up used to determine pressure drop during flow of a two-phase liquid-gas mixture. The main element of the constructed set-up was a channel of rectangular cross section. The channel was built from two polycarbonate plates separated by thin distance slats. This solution enabled gap width to be changed. Two channels of the following dimensions were used:

channel I: 400 mm long, 15 mm wide, gap width $\delta$= 1.23 mm,
channel II: 400 mm long, 15 mm wide, gap width $\delta$= 2.31 mm.

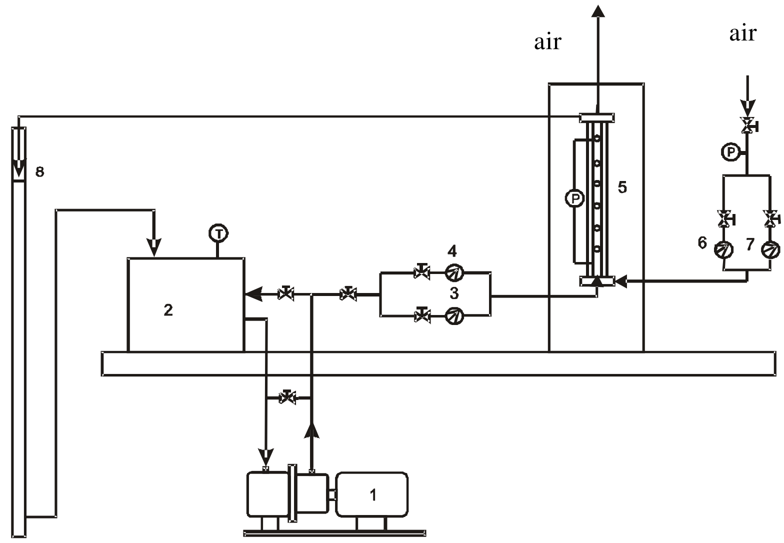


Fig. 1. Schematic of the experimental set-up
1 – MONO pump, 2 – thermostat, 3,4 – MPP 04 electromagnetic liquid flow meters, 5 – minichannel, 6,7 – gas flow meters and control, 8 – deaerating column, T –temperature measurement,

Liquid from thermostat (2) was supplied by a pump to the lower part of the tested channel (5). In parallel, air was supplied through a distributor to the flowing liquid. The gas distributor consisted of five capillaries situated in a line. Liquid and gas were supplied to the minichannel (5) in its lower part where they were mixed. The two-phase mixture was separated after flowing through the channel (5). The air was removed to the atmosphere, while the liquid – after being fully deaerated in the deaeration duct (8) – was recycled to thermostat (2). The volumetric gas stream was measured using thermal meters and gas flow controllers (5) of different flow ranges. The value of gas flow rate was set by means of controllers which were controlled by the Smart Control Software. Pressure of gas supplied to channel (5) was measured by a pressure gauge (P). Volumetric liquid stream was measured by electromagnetic flow meters (3). Transparent polycarbonate used in the minichannel construction enabled observation of the two-phase liquid-gas flow.

The two-phase mixture flowing in the channel was filmed by a Photonfocus MV-D752-160 high-speed camera and the image was recorded on a computer hard disk. A continuous phase in the experiments was water and water solutions of saccharose. Physicochemical properties of the applied media are given in Table 2. The superficial liquid and gas velocities ranged from 0.047 to 2.30 m/s and from 0.011 to 5.65 m/s, respectively.

Table 1. Physicochemical properties of media used in the experiments

| | Viscosity [Pa·s] | Density [kg/m$^3$] |
|---|---|---|
| water | $9.5 \cdot 10^{-4}$ | 998 |
| saccharose solution 1 | $4.0 \cdot 10^{-3}$ | 1160 |
| saccharose solution 2 | $9.7 \cdot 10^{-3}$ | 1185 |

## 2.2 Void friction measurement system

A measuring system consists of a CCD camera placed in front of the channel with two-phase flow, a lighting system and a PC computer equipped with a frame grabber card. Its schematic diagram is shown in Figure 2.

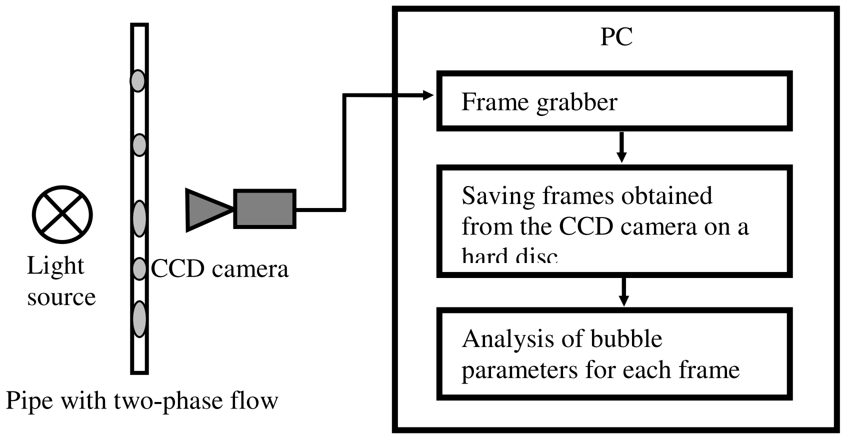


Fig. 2. Schematic diagram of the system to measure gas bubble parameters in two-phase flow

Each frame from the CCD camera is transferred to a PC computer by a frame grabber. Because of high speed of grabbing (about 300 frames/sec) and insufficient computational power, the images are first saved on the hard disc. Their analysis by implemented computer software is effected after an image acquisition process in the off-line system.

The proposed method consists of two algorithms. The first one enables gas bubble area measurement, the second one defines speed vectors in the two-phase flow. The surface area of each bubble is re-scaled from pixels to mm$^2$ according to the formula:

$$A_b = K \cdot \left(\frac{b}{l}\right)^2 \tag{1}$$

The second algorithm allows us to find speed vectors of gas bubbles in two-phase flow. It uses the two consecutive frames *n* and *n*+1. These frames are analyzed separately to specify the surface areas and centers of gravity of gas bubbles by applying the first algorithm. The calculated parameters are used as the features which allow us to find corresponding bubbles in frames *n* and *n*+1. The gas bubble from frame *n*+1 is recognized as corresponding to the bubble from frame *n* if its distance in the feature space to the bubble in frame *n* is the smallest from among all bubbles available in frame *n*+1. Due to the fact that to find a distance traveled by bubbles in time between the two consecutive frames, we used the displacement of their centers of gravity, the areas of corresponding bubbles must be equal. Finally, for each bubble in frame *n* a speed vector is found according to the equation:

$$v = \frac{\Delta d}{\Delta t} \quad (2)$$

Finally, results obtained with the use of the two presented algorithms are saved in text format to file for further analysis.

The presented algorithms for measurement of gas bubbles parameters in two-phase flow are implemented in the LabView 7.1 environment using the Vision packet (Tomczak et al., 2007).

It is known that in the case of steady-state two-phase flow, bubbles which take part in the flow can have different dimensions and flow velocity. Therefore, when calculating mean velocity of gas phase flow, the volumetric fraction of a given bubble should be taken into account. The mean velocity of gas phase flow is calculated from the formula:

$$v_G = \frac{\sum_{i=1}^{n} A_{bi} \vec{v}_i}{\sum_{i=1}^{n} A_{bi}} \quad (3)$$

The velocity of surface area of gas bubbles was determined using the two above mentioned algorithms. The number of analyzed objects n depended on the number of analyzed frames (in the tests 10 frames were taken) and on the flow structure. The value of mean gas phase fraction can be determined also on the basis of the value of surface area and velocity of gas bubbles and superficial gas phase flow velocity.

$$\varepsilon_G = \frac{u_{SG}}{v_G} \quad (4)$$

The superficial gas flow velocity in the channel was calculated from the volume gas stream measured in the experiments, while mean gas flow velocity from equation (3).

## 3. Results and discussion

Gas void fractions determined according to the procedure presented above, are shown in diagrams in dependence on apparent velocities of the flowing gas. Figure 3 shows examples of flow of a two-phase mixture with water solution of saccharose 1 in a channel with gap width $\delta$ = 2.31 mm. It was observed that in the tested measuring range, irrespective of liquid viscosity, the effect of apparent liquid and gas velocity on the gas void fraction was similar to that presented by Triplett et al. (1999).

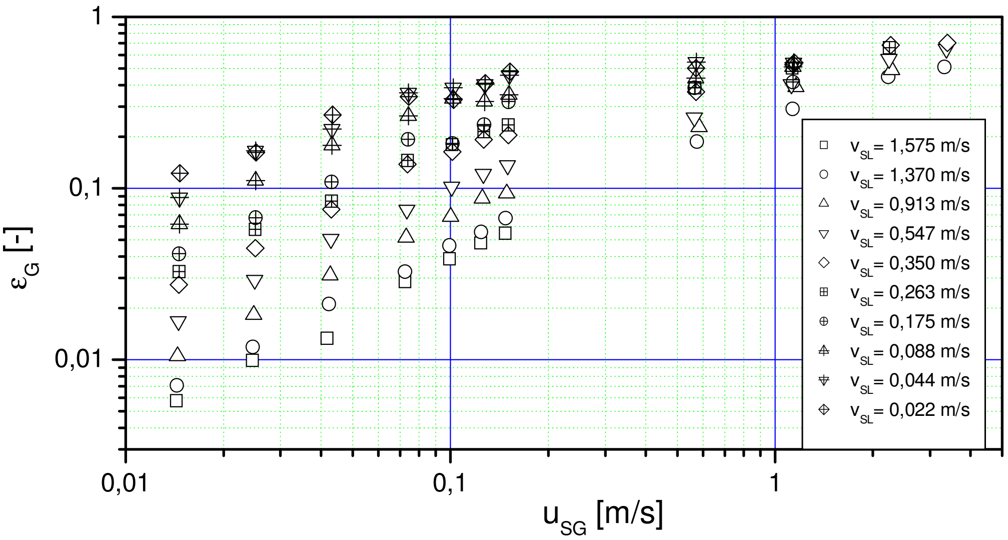


Fig. 3. Dependence of gas void fraction on apparent liquid and gas velocity in a two-phase flow with saccharose 1 solution. Gap width $\delta = 2.31$ mm

Figure 4 illustrates the effect of viscosity of the liquid flowing in a two-phase mixture on gas void fraction. A significant influence of liquid viscosity on gas void fraction can be observed easily. With an increase of liquid viscosity the gas void fraction decreases. An increased liquid viscosity causes an increase of thickness of the liquid film which separates gas bubbles from the channel wall. Due to this, the effective two-phase flow cross section decreases. Figure 5 shows the effect of the gap width on gas void fraction in a two-phase mixture flow. In this case no significant effect of gap width on gas void fraction was observed.

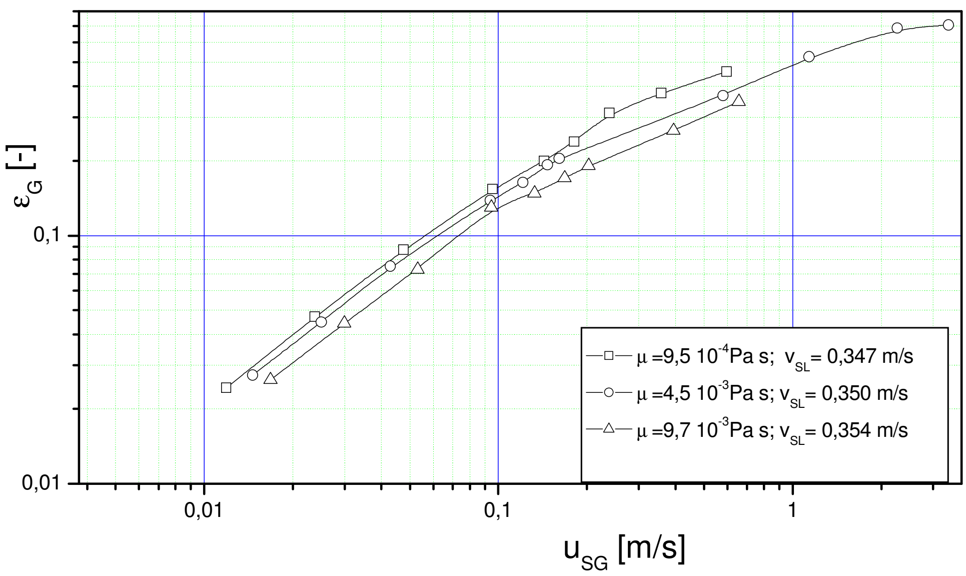


Fig. 4. The effect of liquid viscosity on gas void fraction during two-phase mixture flow in the channel with gap width $\delta$=2.31 mm

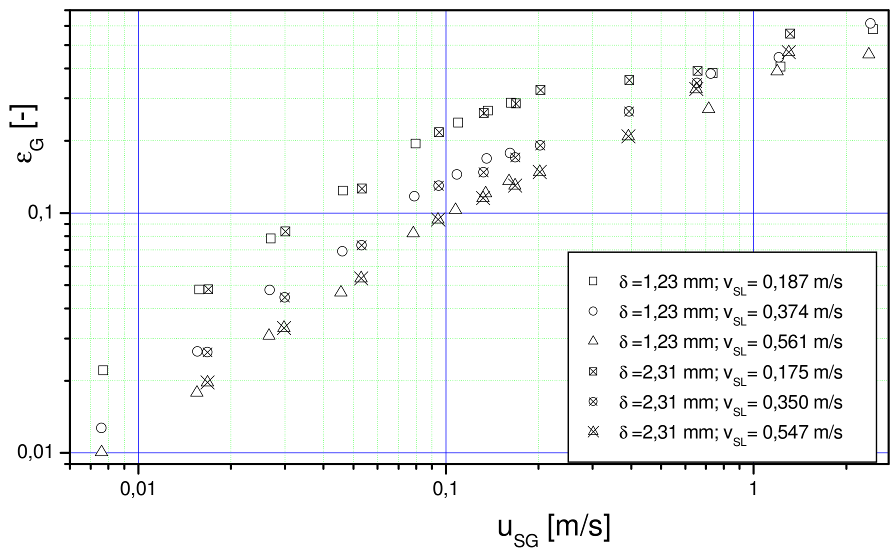


Fig. 5. The effect of gap thickness id on gas void fraction during flow of a two-phase mixture with saccharose solution 2

An attempt was made to correlate the experimental data of gas void fraction by means of a relation based on the drift flux model (Mishima et al., 1996):

$$v_G = \frac{u_{SG}}{\varepsilon_G} = C_0 v_m \tag{5}$$

Examples of experimental data are illustrated in Fig. 6.

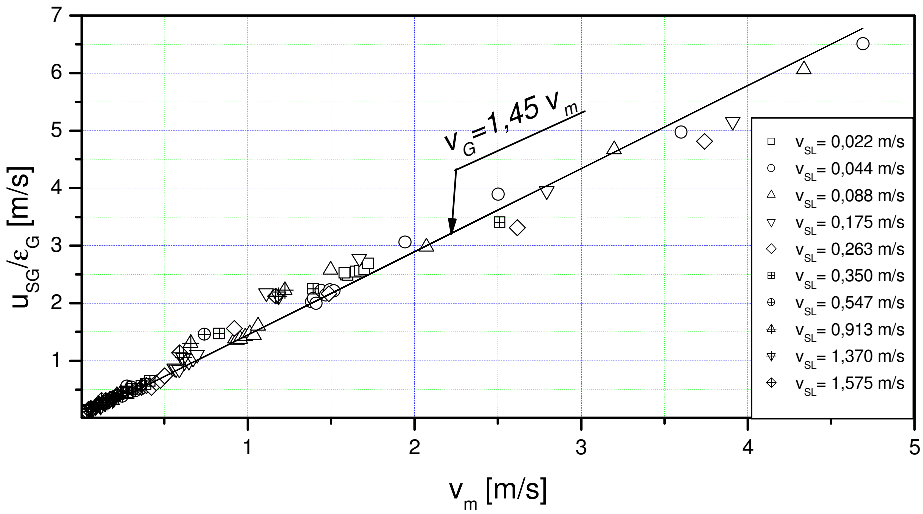


Fig. 6. Drift-flux correlation for saccharose solution 1, δ=2.31 mm

Table 2 gives values of distribution parameter for all tested variants of two-phase flow. An increase of liquid viscosity causes a significant increase of the distribution parameter in both channels. The above mentioned decrease of the effective two-phase flow cross-section area causes an increase of mean flow velocity of the gas phase $v_G$ – which is revealed by a higher value of the distribution parameter $C_0$.

Table 2. Values of distribution parameter $C_0$

| | channel I<br>$\delta$= 1.23 mm | channel II<br>$\delta$= 2.31 mm |
|---|---|---|
| air-water | 1.28 | 1.23 |
| air-saccharose solution 1 | 1.58 | 1.45 |
| air-saccharose solution 2 | 1.76 | 1.68 |

## 4. Conclusions

As a result of experiments and analysis of the experimental data, the following conclusions can be drawn:

- It was confirmed that experimental data concerning void fractions in a liquid-gas mixture flowing in a narrow minichannel could be described by a drift model; constants of the model were proposed.
- Liquid viscosity increase causes a decrease of gas void fraction in the flow of two-phase mixture in a narrow minichannel.
- In the tested range of measurements no distinct effect of the gap width on gas void fraction was reported.
- An increase of liquid viscosity causes a significant growth of mean gas phase flow velocity $v_G$ during two-phase flow in a narrow minichannel.

## Nomenclature

$A_b$ - gas bubble area in pixels, $mm^2$
$C_0$ - distribution parameter
K - gas bubble area in pixels,
b - width of channel with two-phase flow, mm
l - width of channel with two-phase flow in pixels
$u_{SG}$ - superficial gas velocity, m/s
$v_m$ - volumetric mixture flux
v - speed vector of gas bubble, m/s
$\Delta d$ - displacement of the center of gravity of a gas bubble in frames *n* and *n*+1
$\Delta t$ - time between frames *n* and *n*+1, s
$\delta$ - gap width, m
$\varepsilon_G$ - gas void fraction

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