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Some problems of hydrodynamics of two-phase flow mixtures in minichannels

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Abstract Gas-liquid two-phase flow in minichannels has been the subject of increased research interest in the past few years. Evaluation, however, of today's state of the art regarding hydrodynamics of flow in minichannels shows significant differences between existing test results. In the literature there is no clear information regarding: defining the boundary between minichannels and conventional channels, labelling of flow patterns. The review of literature on the hydrodynamics of gas-liquid flow in minichannels shows that, despite the fact that many research works have been published, the problem of determining the effect of diameter of the minichannel on the hydrodynamics of the flow is still at an early stage. Therefore, the paperpresents the results of research concerning determination of flow regime map for the vertical upward flow in minichannels. The research is based on a comprehensive analysis of the literature data and on the research that has been carried out. Such approach to the mentioned above problems concerning key issues of the two-phase flow in minichannels allowed to determine ranges of occurrence of flow structures with a relatively high accuracy.

Keywords: Two-phase flow; Minichannel; Flow pattern; Flow regime map

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Nomenclature

A	–	annular flow
B	–	bubble flow
DB	–	dispersed bubble flow
D_h	–	hydraulic diameter, mm
F	–	froth flow
FA	–	annular-froth flow
I	–	intermittent flow
S	–	slug flow
SF	–	slug-froth flow
w	–	velocity, m/s
w_{sg}	–	superficial gas velocity, m/s
w_{sl}	–	superficial liquid velocity, m/s

Subscripts

g	–	gas phase
l	–	liquid phase

1 Introduction

Presently production of heat exchangers with their tooling, especially in micro- and miniscale is a dynamically developing branch of the energy industry. Mostly it concerns compact heat exchangers, micro and mini pumps and mini- and microchemical reactors. The necessity to dissipate more and more heat, which is generated in high powered electronic systems is also an important problem. Additionally, rational use of energy and environment protection plays a dominant role in designing energy engines and devices. Additionally, rational use of energy and environment protection plays a dominant role in designing energy engines and devices. Integrated parts of compact heat exchangers, widely used in industry are the minichannels. Therefore, detailed knowledge of hydrodynamics of two-phase gas-liquid mixtures is so important. On the basis of literature review it can be noticed that any of the basic flow parameters, like void fraction or flow regimes, have been studied sufficiently. It is worth to emphasize, that flow structures are one of the most important parameters in two-phase flow. They affect phenomena of the momentum, heat and mass transport, and in consequence determine the way of defining the void fraction or pressure drop, Dziubiński and Prywer [5], Waelchli and Rohr [10] and Yang and Shieh [12]. The objective of this paper is to show some problems of two-phase flow hydrodynamics in minichannels especially from the point of view flow maps.

2 Study conception

A special test section (Fig. 1) has been designed and constructed, giving possibility to observe and register the mixture flow.

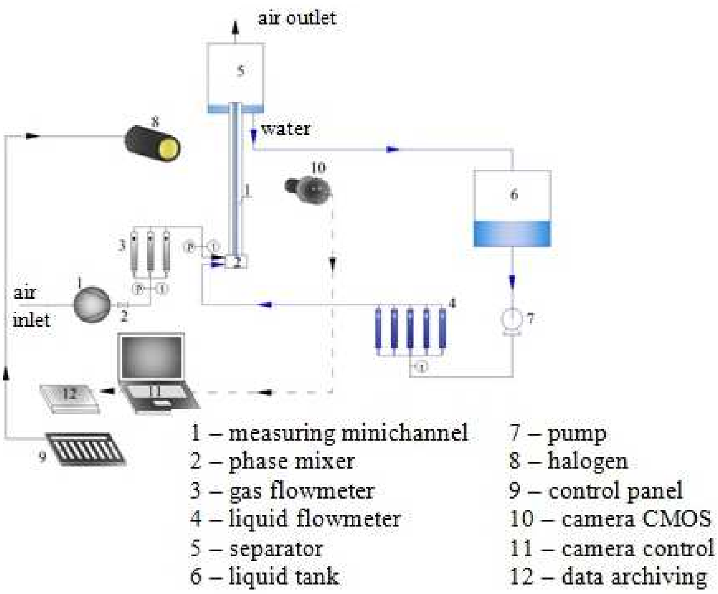
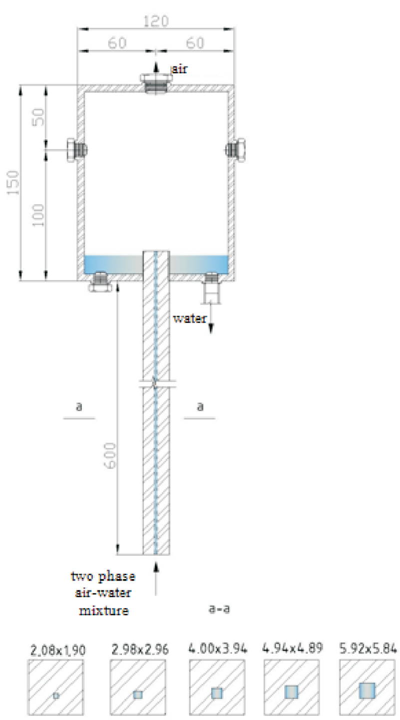


Figure 1: Scheme of test section.

Five different diameters of the minichannels, ranging from 2 to 6 mm for upward cocurrent air-water flow were applied. A noninvasive visual method based on digital image processing was used. Effective and advanced tool can be used for studying the hydrodynamics in apparatus with complicated geometry. The basic element of the installation was a vertical measuring channel in five different variants of the hydraulic channel diameters (Fig. 2). Since square channels have a greater heat exchange surface and allow for better apparatus compactness than circular channels, experiments were carried with applying the square minichannels. In addition Coleman and Garimella [4] concluded that the effect of shape of minichannel on the boundary transitions between flow structures is negligible. Moreover, that choice of the channel geometry enabled best quality of flow visualization.

The two-phase flow in the channel was registered with the aid of high speed camera. Recorded sequence of bit maps were the base to next analyzes. Figure 3 shows registration area in measuring minichannels and ob-



Actual dimension [mm]		Actual diameter	Nominal diameter
a	b	D_h [mm]	
2.08	1.90	1.99	**2**
2.98	2.96	2.97	**3**
4.00	3.94	3.97	**4**
4.94	4.89	4.88	**5**
5.92	5.84	5.88	**6**

Figure 2: Geometry of examined minichannels.

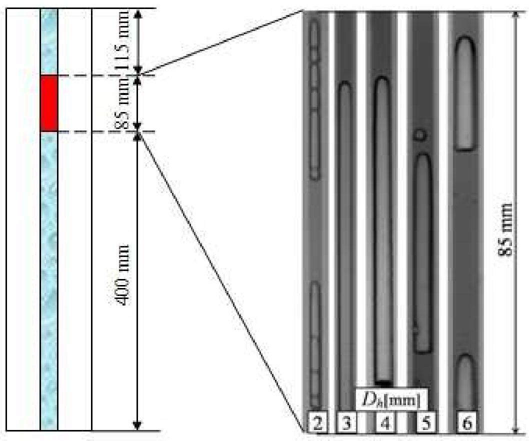


Figure 3: Registration area (marked rectangle) and exemplary observed flow structures (w_{sg} = 0.14–0.16 m/s and w_{sl} = 0.70–0.75 m/s.)

tained exemplary bit maps presenting flow structures. Recently this method of visualization, which allowed a noninvasive identification of the flow structure in minichannels was used also in other research [14].

3 Flow maps in minichannels

3.1 Comparison between results of own studies with the data from other investigations

It was decided to conduct comparison of the obtained experimental results with the results from literature. Several often quoted flow maps were chosen for the analysis (Tab. 1).

Table 1: Characteristics of the data base used for comparative analysis of the two-phase flow ($D_h = 2$ mm).

		Chen *et al.* [3]	Mishima, Hibiki [9]	Fukano, Kariyasaki [6]	Ide *et al.* [8]
Symbol		—— · ——	□, B, x, S, *, A, 28 points	....	————
D_h [mm]		2.01	2.05	2.4	2.0
Cross section		Circular			
Working medium		R134a	air/water	air/water	air/water
Pressure [MPa]		0.6	0.1	0.1	0.15
Temperature [°C]		20–55	20	20	18–24
Flow structure		DB, B, S, F, A	B, S, A	$\mathcal{B}, \mathcal{I}, \mathcal{A}$	*B, S, F, A*
Superficial velocity [m/s]	gas	0.01–10.0	0.1–50.0	0.1–30.0	0.5–30.0
	liquid	0.04–5.0	0.02–2.0	0.03–2.0	0.1–2.0

DB – dispersed bubble, S – slug, A – annular, B – bubble, F – froth, I – intermittent

Figure 4 presents the effect of comparison between range of occurrence of particular flow structures in case of own experiments and results from above mentioned maps (Tab. 1) for the minichannel of $D_h = 2$ mm. Presented graphical analysis allowed to determine common parts of ranges of particular flow structure occurrence (Fig. 5). The general statistic correspondence between the flow structures obtained from present experiments with the map by Chen *et al.* [3] and by Ide *et al.* [8] accounted for 42.8% in both cases. Better result has been obtained from comparative analyzes with the map by Fukano and Kariyasaki [6] namely about 84.5%. This satisfactory

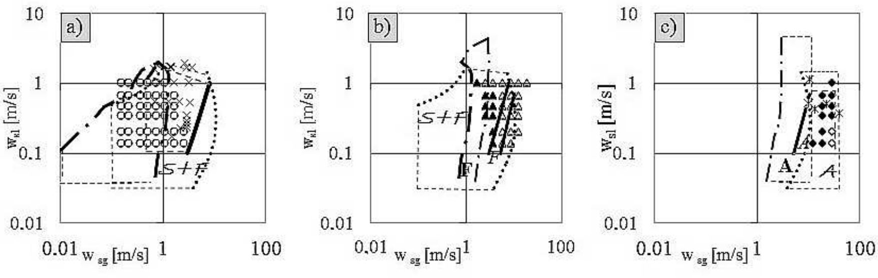


Figure 4: Comparison of ranges of flow structures occurrance in minichannel, D_h = 2 mm, with maps described in Tab. 1 for: a) slug: S; b) slug-froth, froth: SF+F; c) froth-anullar, annular: FA+A.

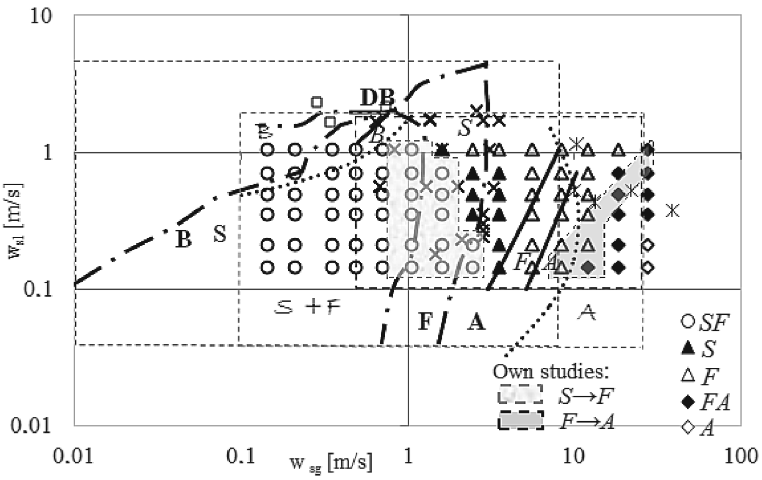


Figure 5: Comparison of present results with other available data (Tab. 1), D_h = 2 mm.

consistency arises from the fact that the common area for the slug and froth structure as intermittent flow had been determined. On the basis of obtained results and data base of other studies, a new, universal flow map for upward two-phase flow in minichannels has been proposed. Generally, because of limited scope of own experiments it is difficult to conclude about quantitative correspondence. However, in case of froth and annular flow a trend in location of boundary transition on the flow maps can be noticed (Fig.6).

Conducted comparative analysis has allowed to determine the boundary transition between the above mentioned flow regimes. Finally based on

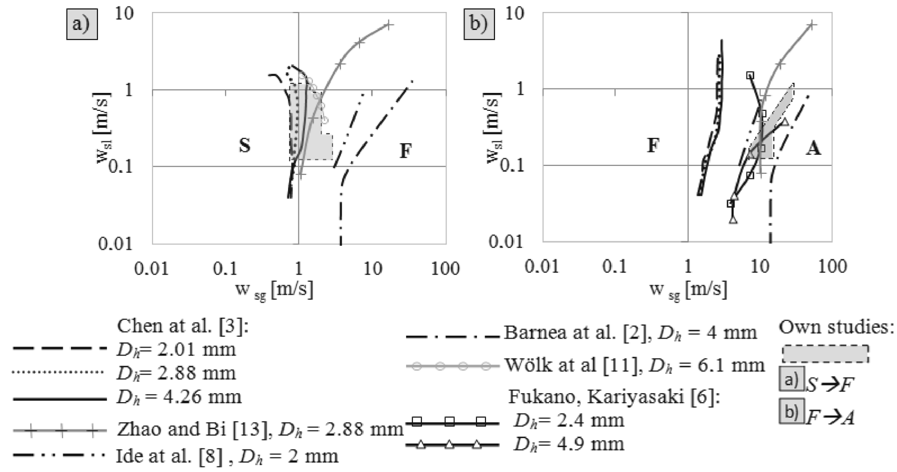


Figure 6: Boundary transitions according to analyzed flow map between: a) slug-froth b) froth-anullar.

good consistency between presented results and the ones from experiments carried by Zhao and Bi [13], the transition line between slug and froth flow structures was established as according to [13]. In relation to boundary transition between the froth and annular flow the line has been established as a result of superimposing of two lines: from Fukano and Kariyasaki ($D_h = 2.4$ mm) [6] and Zhao and Bi [13] and further according to beginning of annular flow structure generation in own experiments. As a result of conducted analysis in Fig. 7 a proposal of flow map has been presented.

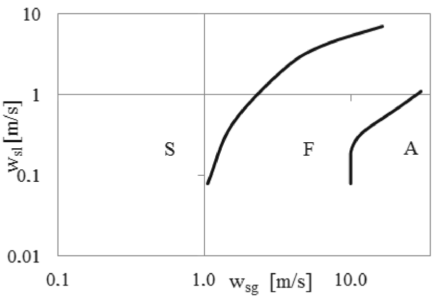


Figure 7: Proposal of flow map for minichannels.

3.2 Comparison of proposed own flow map with universal maps for the minichannels

The universal flow maps by Hassan *et al.* [7] and by Akbar *et al.* [1] were compared with the results from elaborated map (Fig. 8). The comparative analysis with Hassan map showed a poor correspondence, near 61.1%. On the other hand, the effect of comparison of obtained results with the map proposed by Akbar *et al.* [1] confirmed the propriety of assumption that for the two-phase flow in minichannels in range for hydraulic diameter of 2–6 mm the flow structures may be determined with the aid of postulated flow map.

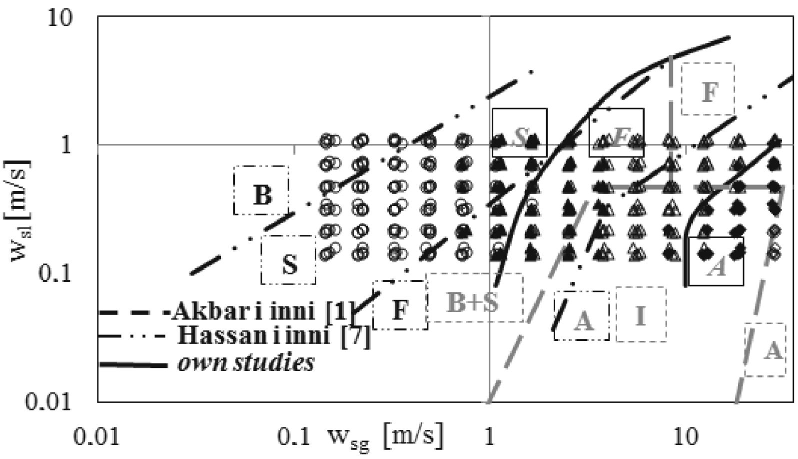


Figure 8: Comparison of experimental results, proposed new map with universal maps from literature.

4 Conclusions

On the basis of conducted literature review, concerning current knowledge about two phase flow in minichannels, and the results of own experiments with upward air-water mixture flow in minichannels of hydraulic diameter in range of 2 to 6 mm, a new flow map has been proposed. It was confirmed that by means of that map the flow structures may be determined with the approximate correspondence of 86%.

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