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Experimental investigations of Poiseuille number laminar flow of water and air in minichannels

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ABSTRACT

This paper presents the results of experiential investigations of pressure drop in minichannels, with use of water and air as the working fluids. The test section was made from stainless steel pipes with internal diameters of 0.55, 0.64 and 1.10 mm, respectively. A pressure drop was presented per a length unit as the function of Reynolds number. A comparison of the experimental friction factor with the results obtained from theoretical equations of Hagen–Poiseuille was presented. The experiments were conducted in range of Reynolds number $Re = 30$ up to transition to the turbulent flow.

Contradictory reports concerning a sooner transition to the turbulent flow, or the friction factor values which diverge from those occurring in conventional channels, were not confirmed here.

1. Introduction

Together with the technological advancement, heat exchangers of a size much smaller than that of exchangers generally known as conventional are becoming more and more common. Sample areas of the application of this type of exchangers are as follows: car industry – air conditioning systems; electronic industry – cooling of elements generating heat, fuel cells; housing industry: air conditioners, heat pumps. The application of heat exchangers of this type is becoming the more common the more their sizes are reduced, and the manufacturing technology more available.

Heat exchangers in which channels of this type are used have their advantages. These include the following: the possibility of work with higher working medium pressures, a much greater contact zone of the medium with the channel wall in relation to the liquid volume unit, a substantially smaller mass of the refrigerant applied, experimentally confirmed higher heat transfer coefficients, a lower wear of materials, or a smaller weight of the whole system. In the case of a depressurization of the system, the mass of the medium which will get to the environment is very small, which is advantageous both to a decrease of gases which cause the greenhouse effect and a degradation of the ozone layer. A drawback of compact heat exchangers is an increase of flow resistances together with a decrease of the hydraulic diameter of the channel as a result of the relative roughness increase. Another disadvantage is, with favorable conditions, a fluctuation of the flow cause by an abrupt increase of bubbles.

In spite of the existence of numerous experimental and theoretical examinations, a certain number of the main hydrodynamic aspects have not received sufficient research. There are contradictory data concerning flow in this type of channels, such as the criterion of transition from the laminar to turbulent flow, or compatibility of the friction factor in laminar and turbulent flow with Hagen–Poiseuille law and Blasius equation respectively, valid for channels of classical sizes. This leads to difficulty of understanding the idea of the phenomena and constitutes the basis for very disputable discoveries. Discrepancies between the data have been interpreted as a disclosure of unknown effects of flow in small channels. However, the reason may be the fact that the conditions of the experiments were not identical with the conditions which were used for the formulation of theoretical models.

2. Studies of single-phase flow in minichannels

Pehlivan [1] made experimental investigations of the pressure drop of two-phase flow of water–air in channels with a circular section with an internal diameter of 3, 1 and 0.8 mm. In the part concerning pressure drop of single-phase flow, he confirmed both for water and air a compliance of Poiseuille conventional theory for laminar flow and Blasisus theory for turbulent flow with the experimental results for minichannels.

Celata [2] examined the effect of a wall surface on the behavior of a liquid flowing inside channels with a circular section and internal diameters from 0.326 to 0.070 mm. The friction factor obtained

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Nomenclature

C^*	normalized friction coefficient
d	internal diameter (m)
L	length (m)
$\dot{m}$	mass flow rate (kg/s)
Δp	pressure drop (Pa)
Po	Poiseuille number
Re	Reynolds number
w	mean velocity (m/s)
x	distance from inlet to pipe (m)
x^+	dimensionless length

Greek symbols

λ	friction factor
μ	dynamic viscosity (Ns/m^2)
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)

could in every case be correctly predicted by the dependencies valid for conventional channels.

Similar conclusions are presented in papers [3–6].

Hwang [7] made an investigation of pressure drop in circular minichannels made from stainless steel. In a review of the literature, he provides a tabular list of studies from which it is evident that the friction factor is larger that it results from theory (five studies); compliant with the theory (four studies) or smaller (four studies). The results of his experiments conducted on pipes with internal diameters of 0.244, 0.430 and 0.792 mm were compliant with the forecasts of the classical theories, while the transition flow started with Re slightly smaller than 2000.

Hetsroni [8] in his survey article presents a list of results of experimental investigations of the single-phase flow through smooth and rough channels with various shapes of cross sections. Hydraulic diameters were from 4.010 to 0.003 mm. The boundaries of a transition from laminar to turbulent flow occurred from $Re = 300$ to $Re = 3800$, while the value of Poiseuille's number exceeded the theoretical values by even as much as 37%.

Wang [9] examined the friction coefficient during the flow of water and lubricating oil through channels with a circular and rectangular cross sections with hydraulic diameters d_h = 2.01–0.198 mm. The experimental values obtained of the friction factor for oil in rectangular channels were 10–30% lower, while for water slightly lower from those obtained in the theoretical way.

Agostini [10] made research into the heat transfer coefficient and the pressure drop of liquid R134a flowing in rectangular channels with hydraulic diameters of 1.17 and 0.77 mm. The results obtained of the investigation into the flow pressure drop were substantially higher (up to 50%) than those obtained from Shah-London's equation for laminar flow and from Blasius equation for turbulent flow, especially for the channel with greater dimensions. In paper [11], Agostini presents the result for flow R134a through eleven parallel channels with a rectangular section (d_h = 2.01 mm). As the laminar single-phase flow occurred, a good agreement was obtained with Shah and London's correlation, and as turbulent flow occurred, with Colebrook's equation.

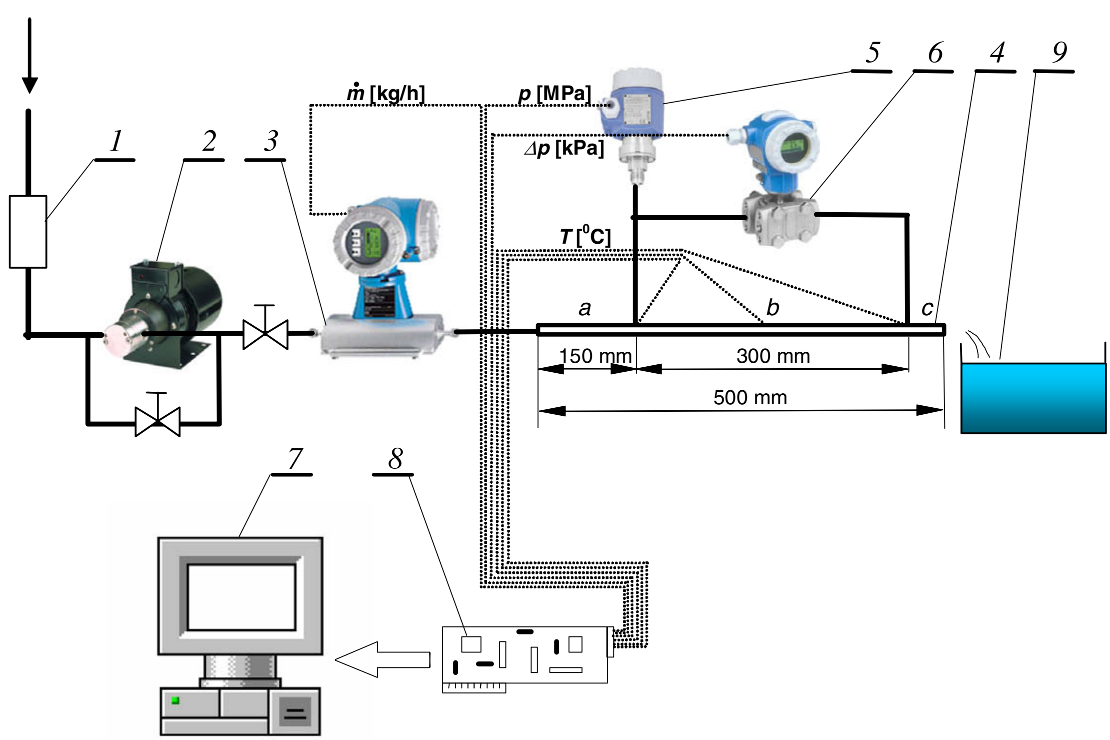

Fig. 1. Experimental set-up: 1 – filter, 2 – pump with valves (compressor if air flew) and adjustment valve, 3 – flow meter, 4 – test section, 5 – pressure transducer, 6 – difference pressure transducer, 7 – computer, 8 – measurement card, 9 – tank; (a–c) zones of the test section.