International Journal of Heat and Mass Transfer 52 (2009) 5185–5192

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Two-phase pressure drop of air–water in minichannels

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ARTICLE INFO

Article history:
Received 15 August 2008
Accepted 27 April 2009
Available online 12 June 2009

Keywords:
Minichannels
Experimental data
Two-phase flow
Pressure drop
Lockhart–Martinelli
Friedel

ABSTRACT

Results of experimental investigations of pressure drop in two-phase adiabatic flow in tubular minichannels are presented. Air–water mixture was used as a working fluid. Eight tubular minichannels with internal diameter $d_w = 1.05 \div 2.30$ mm and the test section length of 300 mm made from stainless steel were used. The investigations were conducted within the range: mass flow rate of water $0.65 \div 59$ kg/h, mass flow rate of air $0.011 \div 0.72$ kg/h, mass fraction of air in the two-phase mixture $x = 0.0003 \div 0.22$, total mass flux $(w\rho) = 139 \div 8582$ kg/(m^2 s). It was found, on the basis of the experimental investigations, that the application of commonly used methods to evaluation of pressure drop in two-phase flow, provided poor results. It is therefore necessary to make some corrections and modifications for the two-phase flow in minichannels correlations.

1. Introduction

At present, an increasing attention is being paid to heat transfer from small elements, which generate large amounts of heat. These elements include above all elements of electronic devices, including microprocessors. The methods used so far for cooling with the employment of gaseous or liquids mediums do not guarantee receive a very large heat fluxes. For this reason, more and more often, the possibilities of heat exchange during phase change of the refrigerant in the flow in channels are used. One should note that the elements in which the cooling process is realized have very small dimensions, and for this reason, the flow of the boiling medium occurs in the so-called minichannels. According to the classification given by Kandlikar [1–4], these are channels with a hydraulic diameter in range of $0.2 \div 3$ mm. With the increase of the flow rate in such channels, an intensive growth of flow resistances occurs. The knowledge of the value of the flow resistance of the medium is important as it facilitates, among others, the selection of the devices which generate the flow.

The designer of a compact evaporator, built on the basis of minichannels, faces an important dilemma at present, which concerns the selection of suitable calculation methods for the flow resistance of boiling mediums in minichannels. The first question which was considered in this problem was: is it possible to use those calculation procedures which have been known for many years and are well-tried with respect to the flow in conventional channels for minichannels.

The paper presents the results of experimental investigations which were conducted to check-out whether the Lockhart–Martinelli and Friedel methods may be used for calculation the two-phase pressure drop also during the flow in minichannels. A mixture of water and air was used as a model medium.

2. Experimental investigations

2.1. Experimental set-up

Fig. 1 presents a schema of the experimental set-up. Water was pumped by a mini-gear pump 2 (D Series Magnetically Coupled Gear Pump manufactured by Tuthill Corporation) and was supplied to the mixing zone 3 and further to the measuring section of a tubular minichannel 4. A system of valves in the instrumentation of the pump 2 controls the water flow rate. Air was supplied by a compressor 1, through a control valve and a system of filters, to a mass flowmeter Coriolis 5 (Promass 80A manufactured by Endress + Hauser). The measuring range of the flowmeter was $0 \div 20$ kg/h and the class of 0.15. It enabled an accuracy of ±0.03 kg/h. The measuring range of the flowmeter could be changed and an increase of the measuring accuracy could be achieved at lower flow rates. The water and air filters were important elements of the experimental set-up which prevent minichannels before its destruction. The pomp as well as the compressor were next to stable construction where test section was fixed. That solution protected main construction from vibrations.

The measuring Section 4 constituted the main element of the test facility. Minichannels with a circular cross section made from stainless steel, with a total length of 500 mm and the internal diameters: 1.05, 1.30, 1.35, 1.40, 1.60, 1.68, 1.94 and 2.30 mm were used.

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doi:10.1016/j.ijheatmasstransfer.2009.04.018

Nomenclature

A	cross section (m^2)
C	Chisholm parameter
d	diameter (m)
ΔL	length of test section (m)
Δp	pressure drop (Pa)
Fr	Froud number
g	gravitational acceleration (m/s^2)
j	superficial velocity (m/s)
$\dot{m}$	mass flow rate (kg/s)
Re	Reynolds number
We	Weber number
$(w\rho)$	mass flux (kg/m^{2}s)
x	mass fraction of gas in two-phase mixture (vapour quality)

Greek symbols

χ	Lockhart–Martinelli parameter
φ	two-phase frictional multiplier
λ	friction factor
μ	dynamic viscosity (Ns/m^2)
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ	surface tension (N/m)

Subscripts

a	acceleration
g	gas phase
go	all mass is assumed as gas only
H	hydrostatic
HOM	homogeneous
l	liquid
lo	all mass is assumed as liquid only
TP	two-phase
TPF	two-phase frictional
w	internal

The total length of the measuring minichannel was divided into three sections: entrance section "a", the main section "b" and outlet section "c" (in Fig. 1, marked with a, b, c symbols, respectively). The first section was a stabilizing section with the length of 150 mm starting from the inlet cross-section. The second, insulated section "b" with the length of 300 mm was the main measuring section. The last one, outlet section "c" was 50 mm of length. Water which left this section entered tank 10. The method so-called "the method of the filling of the tank" was used to determine the flow rate of water. The description of this method was presented in paper [5], among others. It enabled a precise measurement of very small flow rate of water. The evaluation of the measuring error for the flow rate of water was made comparatively with the use of a Coriolis mass flowmeter. It was found that the uncertainly of this method does not exceed ±5% of the measured value.

The impulse holes were made for the measuring local pressure and pressure drop of the fluid. On the inlet to the measuring section "b", local pressure of mixture was measured. The piezoresistant sensor with a transducer 6 (Cerabar M PMP41 manufactured by Endress + Hauser) was used for the inlet static pressure measurement. This pressure transducer was the measuring range of 0 ÷ 1 MPa. The accuracy of this pressure transducer does not exceed 0.2% of the measurement range. This gives a pressure measuring uncertainly of ±2 kPa. The pressure drop of the air–water mixtures was measured by a precision differential pressure transducer 7 (Deltabar S PMD75 manufactured by Endress + Hauser), which has an adjustable span. The basic measuring range of pressure transducer was in range of 0 ÷ 500 kPa and its accuracy was 0.075% of measurements. The uncertainly of the differential pressure in the maximal value was ±0.375 kPa.

The temperature of the working medium in the measuring section (b: Fig. 1) was measured using K type thermocouple with the diameter of wires $\phi = 0.2$ mm, placed on the wall in the inlet, outlet and in the middle of the test section. In the range of 10 ÷ 30 °C individual characteristics of these thermocouples, using the laboratory thermometer having an elementary scale of 0.1 °C were made.

The measuring section was insulated with a 10 mm silicone isolation. The experiment was performed at the room temperature

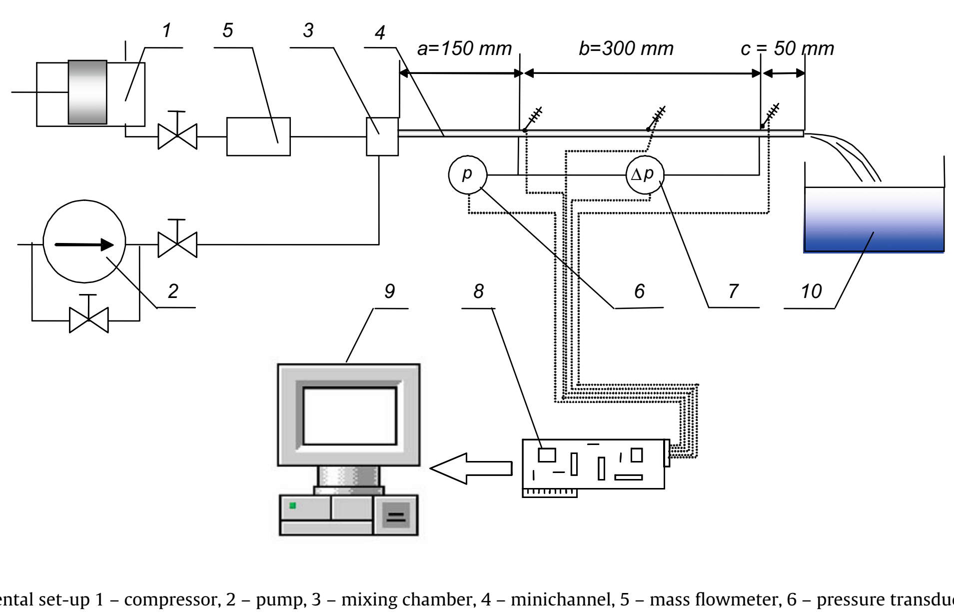

Fig. 1. Schema of experimental set-up 1 – compressor, 2 – pump, 3 – mixing chamber, 4 – minichannel, 5 – mass flowmeter, 6 – pressure transducer, 7 – difference pressure transducer, 8 – measuring card, 9 – PC, 10 – tank, a,b,c – zones of the test section.