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# Two phase flow pressure drop in multiport mini-channel tubes using R134a and R32 as working fluids

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In this study, two-phase flow pressure drop was experimentally measured in condensation and evaporation fluid flow. Refrigerants R134a and R32 were tested in a multiport extruded aluminium tube (MPEs) with hydraulic diameters of 0.715 and 1.16 mm. Experimental conditions were in a range: mass velocity 200–1229 $kg/m^2s$, heat flux 2.55–70 $kW/m^2$, saturated temperatures (5,7.5,12.5,30,35,40,45,50,55) °C. To do so, two installations have been used. They were constructed at the Technical University of Cartagena Spain, for the study of boiling and condensation in tubes. They are briefly described in this paper jointly with the experiments performed. The experimental data are compared with some well-known correlations which were developed for macro/mini-channel tubes. The homogeneous mixture model slightly underestimates the experimental boiling data. Classic macro-channel correlations: Friedel and Müller-Steinhagen and Heck predict satisfactorily well our experimental pressure drop data. Some of the new correlations specially developed for mini/micro-channels have been tested, finding that Cavallini et al. and Zhang and Webb predict with reasonable accuracy the experimental two-phase flow pressure drop data.



## 1. Introduction

Nowadays, mini/micro-channels are present in many applications ranging from different heat exchangers in the process industry to automotive, electronics and domestic applications. The high efficiency of these systems, the low refrigerant charges they need, and the compactness of the equipment are the main reasons that make them so appealing. The characterisation of pressure drop is very important for the design of compact heat exchangers. In recent decades many studies have been carried out in order to characterize pressure drop and heat transfer in mini-channels with different refrigerants and geometries. This work is focused on the two-phase flow pressure drop.

Many authors relate the two-phase frictional pressure gradient and the single phase pressure gradient through a two-phase multiplier. In most cases, they try to include the effect of the refrigerants, the thermodynamic conditions, the geometry, the surface tension, and so on. Lazarek and Black's [1] work is one of the pioneer studies dealing with small-diameter tubes. They proposed an expression based on the Chisholm [2] multiplier with a constant value of the C parameter. More than a decade after, Mishima and Hibiki [3] also used the Chisholm [2] multiplier equation and obtained a modified Chisholm parameter C as a function of the diameter according to their experimental data. Tran and Co-workers [4] proposed a correlation for pressure drop based on the B-coefficient method developed by Chisholm [5]; providing a correlation for the liquid only two-phase multiplier. Zhang and Webb [6] performed an experiment to measure two-phase pressure drop under adiabatic conditions and showed that the Friedel [7] correlation did not predict their experiments well. They provided an expression for the liquid only two-phase multiplier which included the effect of the reduced pressure. Koyama et al. [8] showed that their experimental data were well predicted by the Mishima and Hibiki correlation [3]. In Koyama et al. [9], new data were included to the database studied in the previous works and a pressure drop correlation was developed for the four multiport tubes tested. This correlation is also based on the estimation of the

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## Nomenclature

| | |
|---|---|
| $A_t$ | heat transfer area ($m^2$) |
| $A_r$ | refrigerant free flow area ($m^2$) |
| $Bo$ | bond number (–) |
| $C$ | chisholm parameter (–) |
| $c_p$ | specific heat capacity (J/kg K) |
| $d_h$ | hydraulic diameter (m) |
| $dp$ | pressure drop (Pa) |
| $F_r$ | Froude number (–) |
| $f$ | friction factor (–) |
| $G$ | mass velocity (kg/$m^2$ s) |
| $h$ | specific enthalpy (J/kg) |
| $I$ | current (A) |
| $L_a$ | Laplace number (–) |
| $L_h$ | heating length (m) |
| $L_t$ | total length of the test section (m) |
| $L_{tp}$ | two-phase flow length (m) |
| $\dot{m}_r$ | mass flow rate (kg/s) |
| $MRD$ | mean relative deviation |
| $MARD$ | absolute relative deviation |
| $MPEs$ | multiport extruded tube |
| $P_{int}$ | internal perimeter (m) |
| $P_R$ | reduced pressure (–) |
| $p$ | pressure (Pa) |
| $\dot{Q}$ | power (W) |
| $\dot{q}$ | heat flux (kW/$m^2$) |
| $Re$ | Reynolds number (–) |
| $R_a$ | roughness ($\mu m$) |
| $T$ | temperature (°C) |
| $U_E$ | expanded uncertainty |
| $u_c$ | combined uncertainty |
| $V$ | voltage (V) |
| $We$ | Weber number (–) |
| $x$ | vapour quality (kg/kg) |
| $y$ | measured variable (–) |
| $z$ | coordinate (m) |
| $z_s$ | single-phase flow length (m) |

*Greek symbols*

| | |
|---|---|
| $X$ | Lockhart-Martinelli parameter |
| $\phi$ | two-phase frictional multiplier |
| $\rho$ | density (kg/$m^3$) |
| $\mu$ | dynamic viscosity (Pa s) |
| $\sigma$ | surface tension (N/m) |

*Subscripts*

| | |
|---|---|
| $ac$ | acceleration |
| $c$ | contraction |
| $ch$ | channel |
| $crit$ | critical |
| $e$ | expansion |
| $Evap$ | evaporator |
| $F$ | Frictional |
| $\mathscr{g}$ | gravitational |
| $g$ | pure vapour |
| $go$ | vapour only |
| $i$ | inlet |
| $l$ | pure liquid |
| $lo$ | liquid only |
| $ll$ | Laminar–Laminar |
| $lt$ | Laminar-Turbulent |
| $meas$ | measured magnitude |
| $o$ | outlet |
| $r$ | refrigerant |
| $tl$ | Turbulent-Laminar |
| $tp$ | two-phase flow |
| $ts$ | test section |
| $tt$ | Turbulent-Laminar |
| $sat$ | saturation state |
| $w$ | external wall of the tube |
| $wa$ | water |

vapour two-phase multiplier. They showed that the Friedel [7] correlation worked well at high velocities, but it was not able to predict their data well at low velocities where free convection is important.

Garimella et al. [10–12] considered the different flow regimes taking place during the condensation process and provided expressions that depend on the regime (annular or slug/intermittent flow). Yu et al. [13] measured pressure drop in circular tubes. They found that a power function of the Lockhart-Martinelli [14] parameter correlated quite well with their data. Based on that, the authors proposed a correlation for the pure liquid two-phase multiplier. Cavallini et al. [15] studied adiabatic pressure gradient inside multi-port mini-channels. They found that the Friedel [7], Zhang and Webb [6], Mishima and Hibiki [3] and Müller-Steinhagen and Heck [16] correlations are in good agreement with their experimental pressure drop data. Cavallini et al. [17] proposed an update of their frictional pressure drop model with several mini-channel tubes and hydraulic diameters ranging from 0.4 to 3 mm. They used as working fluids a wide range of reduced pressure refrigerants; R236ea, R134a, and R410A.

Revellin and Thome [18] investigated the two-phase flow pressure drop with R134a and R245fa with diameters of 0.509 mm and 0.790 mm in adiabatic conditions. They observed that the two-phase flow friction factor has similar behaviour to the single-phase flow friction factor in Moody diagram. They reported that the Müller-Steinhagen and Heck [16] correlation works reasonably well for turbulent regime ($Re > 8000$), the other tested correlations fail to predict their experimental pressure drop data. Also a new equation for the friction factor in the homogeneous model was developed for each diameter tested, respectively. Choi et al. [19] performed experiments to measure two-phase flow pressure drop in two horizontal stainless steel tubes with inside diameter of 1.5 mm and 3 mm and R410A as working fluid. They observed that two-phase flow pressure drop is strongly influenced by diameter and mass velocity, thus they developed a new equation of Chisholm parameter on the basis of Lockhart-Martinelli [14] method.

Sun and Mishima [20] reported a new correlation for the Chisholm parameter based on the Lockhart and Martinelli [14] method with 2092 data collected from 18 different published papers, hydraulic diameters ranged from 0.506 mm to 12 mm. They found that Müller-Steinhagen and Heck [16] worked very well for their data. Recently, Kim and Mudawar [21] tried to develop a universal predicting method to evaluate the frictional pressure gradient for adiabatic and condensing flow in mini/micro-channel with 7115 consolidated data from 36 different sources, including HFC refrigerants, air–water, $CO_2$ and hydraulic diameter range 0.0695–6.22 mm.