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Pressure drop in D shaped cylindrical headers of parallel flow MCHXs: Pressure loss coefficients for single phase flow

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HIGHLIGHTS

- Pressure drop for single phase flow through D shaped cylindrical header is studied.
- The non-uniformity of pressure loss coefficient in header is investigated.
- Correlations for pressure loss coefficients for single phase flow are proposed.

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ABSTRACT

This paper presents the investigation of the pressure drop in headers and development of the correlation for pressure loss coefficient for single phase flow through D shaped cylindrical headers of parallel MCHXs. D shaped headers are becoming more popular compared to conventional round cylindrical types due to reduction in charge and pressure drop, despite complexity at difficulties in handling higher pressures. The working fluid was compressed air flowing through header with 1–20 m/s based on smallest cross section while the velocity through microchannels was in the range 4–25 m/s. The experimental results indicate that the pressure loss coefficient of inlet header is a linear function of the ratio of velocities through microchannel tube and header, except for the first two microchannel tubes; the pressure loss coefficient of outlet header is a quadratic function of the ratio of velocities through microchannel tube and header, and decreases as the velocities through upstream microchannel tubes increase. Correlations for predicting pressure drop of inlet header and outlet header are developed and agreement for 98% of experimental data is within ±15 Pa.

1. Introduction

Microchannel heat exchangers show advantages over traditional fin-and-tube heat exchangers in compactness, lower refrigerant charge, etc. Microchannel heat exchangers are dominant in automobile and becoming widely used in residential air conditioning systems [1–4]. However, microchannel heat exchangers face the problem of refrigerant distribution among parallel microchannel tubes [5–11]. The pressure drop in the header strongly affects refrigerant distribution [12,13]. Yin et al. [14] have presented analysis and the model of the pressure drop and mass flow rate distributions through parallel microchannel tubes mostly driven by transcritical R744 applications where MCHXs serves as gas coolers.

Single phase flow is common in inlet headers (gas coolers, condensers, etc.), and outlet headers (DX and FGB evaporators, etc.).

Most commonly found headers have round cylindrical shapes. That design is adopted as the best to handle higher pressures by using pierced tubes, typically seamless. To reduce refrigerant charge, pressure drop and eventual cost, D shaped cylindrical headers are becoming more popular, especially in evaporators and in automotive air conditioning industry. Even these shapes are typically made of sheet metal parts we have made the test samples in this project by adding material inserted in cylindrical headers, not affecting the generality of conclusions. Due to 50% protrusion in round cylindrical header, a big contraction occurs when flow cross over the 1st protrusion, and thus leads to nonuniform pressure loss coefficient along the header [15]. In D shaped cylindrical header,

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Nomenclature

D	diameter (m)
l	length (m)
S	perimeter (m)
v	velocity (m/s)
Greek symbols	
ζ	diverging/converging loss coefficient
λ	frictional loss coefficient
ρ	density (kg m^{-3})
Δp	pressure drop (Pa)
Subscript	
acc	acceleration
c	confluence flow in header
eff	effective friction loss
f	friction
h	hydraulic
i	ith section of header
in	inlet header
o	outlet header
t	tube
tot	total

protrusion is relatively small, normally around 1.0 mm. Therefore, the expectation was that the absence of long protrusion will unify the pressure loss coefficients at various locations.

The single phase pressure drop of microchannel heat exchanger could be broken down in two parts: pressure drop in microchannel tubes and that in headers. The single phase pressure drops in the microchannel tubes are well studied [16–19], and the results showed that the correlation of Churchill [20] has a good prediction for the laminar and turbulent flow regimes in the microchannel tubes. Major problem in defining pressure drop in microchannel tubes is proper determination of the diameter because of significant effect of manufacturing variability. In addition, it is very common to block some channels during brazing when molten filler metal (sometimes clad) enters in the tube due to strong capillary forces. The studies of pressure drop in the header are limited [14,15].

Yin et al. [14] measured pressure drop in headers and generated a model based on the assumption that the pressure loss coefficients are uniform. The results also showed that the pressure loss coefficient in an outlet header is much larger than that in an inlet header. Poggi et al. [15] tested the pressure drop in a round inlet header, and the result shows that the main pressure drop in the inlet header is caused by the contraction when flow passes over the first microchannel tube. However, to the best of author's knowledge, there is still no information about non-uniformity of pressure loss coefficients in D shaped headers. The change of pressure loss coefficient along the header results from the undeveloped flow in headers and the effect of flow through neighboring microchannel tubes.

The flow in inlet and outlet headers is somewhat different: diverging flow in an inlet header and converging flow in an outlet header. The similar cases could be found in the previous studies of flow in T-junctions. The pressure loss coefficients of main flow in the diverging T-junctions are a linear function of the ratio of velocity through side branch and that of main flow and a quadratic function in converging T-junctions, not affected by Reynolds number [21]. Compared with T-junctions, the diverging/converging flow in a header is more complex because: (i) the flow after diverging/converging in a header is not fully developed when an another diverging/converging situation occurs due to the small value of the ratio of tube space between parallel microchannel tubes and hydraulic diameter of header, normally, close to 1; (ii) the flow through upstream or downstream microchannel tubes may affect the flow at the diverging/converging location of interest where the upstream and downstream mean the flow region in the header before and after the diverging/converging location of interest, respectively (see Fig. 3). Therefore, it is necessary to investigate the impacts of undeveloped flow in headers and the effects of flow through neighboring microchannel tubes in order to develop a correction to predict the pressure drop in a header.

This paper presents the investigation of the pressure drop and development of correlation for pressure loss coefficient for single phase flow through round inlet and outlet headers. The results presented in this study are obtained by compressed air. The velocity through headers range from 1 m/s to 20 m/s while the velocity through microchannel tubes is in the range from 4 m/s to 25 m/s, which cover the most of realistic working conditions in the residential and automotive air conditioning system, according to the literature shown in Table 1.

2. Experimental setup and test geometry

The test system consists of a gas tank with constant pressure valve, a temperature pre-conditioner (to equalize the gas temperature with room temperature) and a header connected with 10 microchannel tubes, as shown in Fig. 1. The flow rate is controlled by a needle valve. For the inlet header test flow passes through m_0, and then enters into the header. Part of gas leaves the header through the first 4 microchannel tubes (MC tubes #1 to #4) with each individual mass flow rate measured, and the rest exits to the atmosphere through the header outlet. For the outlet header test, the gas goes through the first five microchannel tubes (MC tubes #1 to #5) with each individual mass flow rate measured, entering into the header, and then exits to atmosphere through header outlet. The mass flow rate transducer m_0 is used to measure the mass flow rate through MC tube #5.

Table 1
Summary of single phase vapor velocities through header and microchannel tube in literature.

Reference	AC type	Heat exchanger type	Ref.	Vapor velocity through header [m/s]	Vapor velocity through MC tube [m/s]
Park and Hrnjak [4]	Residential	Condenser	R410A	3.5	2.2–8.8
Qi et al. [3]	Automotive	Evaporator	R134a	7.4–12.0	11.0–18.0
Pettersen et al. [2]	Automotive	Gas cooler	CO_2	3.9	6.0
Cho and Cho [22]	Residential	Evaporator	R22	10.5–13.4	23–30
Kim and Bullard [23]	Automotive	Evaporator	CO_2	1.6–5.0	5.5–14.7
Tuo et al. [9]	Automotive	Evaporator	R134a	8.7	6.1
Yin et al. [18]	N.A.	Gas cooler	CO_2	5.2–14.4	4.3–12.4
Garcia-Cascales et al. [24]	Residential	Condenser	R410A	1.0–5.5	3.8–20.7
Zhao et al. [25]	Automotive	Evaporator	R1234yf	8.2–17.7	9.8–21.17