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Research Paper

Experimental study on the liquid-side characteristics of meso-channel heat exchangers in fuel cell vehicles

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HIGHLIGHTS

- A study on the liquid-side characteristics of mesochannel radiators was conducted.
- Impacts of inlet parameters on liquid-side thermo-hydraulic performance were analyzed.
- The flow transition from laminar to transitional in mesochannel occurs at Re ≈ 1800.
- Correlations of liquid-side Nusselt number Nu_f and friction factor f_f were proposed.

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ABSTRACT

A meso-channel parallel flow heat exchanger could be used as a radiator for fuel cell vehicles to dissipate waste heat from a fuel cell stack (FCS) to cooling air. Working fluid in tube-side channels was 50% glycol–water mixture. An experiment was conducted on an FCS radiator PFHX A with 2.685 mm hydraulic diameter meso-channels. The influences of condition parameters were analyzed. The critical Reynolds number from laminar to transitional flow in the meso-channels was defined at about 1800. Thus, correlations of heat transfer coefficient Nu_f and friction factor f_f were developed. Compared with some existing correlations, the new correlations correlated better with experimental values. The correlations well predicted Nu_f and f_f for another two radiator samples, PFHX B and PFHX C, with 2.268 mm and 2.295 mm diameter channels. It was suggested that the correlations could be useful for performance prediction and design optimization of meso-channel heat exchangers under extensive operating conditions.

1. Introduction

As a burgeoning type of automotive, fuel cell vehicles provide some noteworthy advantages of energy conservation, low harmful emission and noise. However, its commercialization faces significant technical challenges, among which proper thermal management is the most critical issue. For fuel cell stack systems (FCS) with low efficiency, waste heat load might be up to 40%–60%. AFCS usually operates at a relatively low temperature between 60 °C and 80 °C, a too low or high operating temperature may lead to a voltage loss [1]. Thus, removing waste heat to maintain a moderate working temperature for FCS is necessary and difficult [2,3]. Most of the heat is transferred to a coolant circulating through passages between cell panels, and then the high-temperature coolant is pumped into a radiator to discharge heat to the air. Thus, radiators play a vital role for FCVs to operate steadily and safely. In pursuit of high thermal efficiency, size and weight reduction, a parallel flow heat exchanger has been used. The liquid coolant, usually a water–glycol mixture, flows in large aspect ratio meso-channels (1 mm ≤ D ≤ 3 mm) inside the flat tubes, while the air flows in channels set up by louvered fin surfaces.

In most situations, as the air-side thermal resistance is larger than the liquid-side one, investigations about air-side characteristics of heat exchanger are more extensive [4–9]. Plenty of empirical and theoretical correlations were established for the air-side heat transfer and flow friction characteristic determinations. It is also important to investigate the liquid fluid flow for performance analysis and optimal design of heat exchangers. Numerous research studies [10–17] have been addressed about the heat transfer and pressure drop behaviors of microchannel heat exchangers (D < 1 mm), which have been proven to be different from those of macrochannel heat exchangers (D > 3 mm). Although liquid-side channels of the radiators in automotive application are generally of meso-scale, publications on the heat transfer and pressure drop characteristics of fluid in meso-channels are very limited. Several experiments [18–20] were conducted on radiator tubes or integral heat exchangers to investigate the liquid (water and glycol–water mixture) flow and heat transfer characteristics in meso-channels. Respective correlations of friction factor and heat transfer coefficient were proposed since

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none of the conventional correlations compared the experimental data well. In contrast, the behaviors of R12 and R134a liquid flow in meso-channels in some experiments [21–23] were observed to be very close to that in conventional tubes. Otherwise, there is no consensus on definition of flow regimes in meso-channels. In some reports [19,24,25], flow transitions from laminar to turbulent/transitional in meso-channels occurred at $Re < 2000$. Laminar-turbulent transitions in other meso-channel investigations [21,26] took place at traditional critical Re.

Previous conclusions on flow and heat transfer in meso-channels have been found contradictory and difficult to compare due to different geometries, working fluids and operating conditions. In present study, flow and heat transfer behaviors of large aspect ratio meso-channel heat exchangers were investigated under various test conditions similar to those encountered by FCS radiators. Based on the tested data, ranges of flow regimes in meso-channels were estimated and correlations for f_f and Nu_f were proposed. Furthermore, the new set of correlations was compared with published correlations and validated with experimental data from another two radiators.

2. Experimental setup

As shown in Fig. 1, the experimental setup in an enthalpy difference laboratory includes a thermal wind tunnel, a test chamber, a test heat exchanger, an electromagnetic pump, and a data acquisition system. Both air side and liquid side parameters could be measured.

The wind tunnel could provide air velocity up to 10 m/s. The dry and wet temperatures of inlet air were adjusted by the room air conditioner and humidifier. The air-side temperatures at the inlet and outlet of heat exchanger were measured by platinum resistance temperature sensors. The air-side pressure drop across the heat exchanger was measured by a differential pressure drop transducer. And the air volume flow rate was controlled by a variable speed blower and measured by nozzles installed in the wind tunnel. 50% glycol–water mixture was used as the tube-side working fluid. It was drawn from a reservoir tank by an electromagnetic pump and forced to circulate through the heat exchanger, and then returned to the reservoir tank. Two platinum resistance temperature sensors and two pressure transducers were assembled in the inlet and outlet pipes of the heat exchanger to measure the liquid-side temperatures and pressure drop, respectively. And the liquid flow rate was measured by a turbine flow-meter. The uncertainties of the instruments are listed in Table 1.

Table 1
Experimental uncertainties.

Parameter	Uncertainty
Air-side temperature t_a [°C]	±0.1
Air-side pressure drop P_a [Pa]	±0.25%
Air-side volume flow rate G_a [m^3/s]	±1%
Liquid-side temperature t_f [°C]	±0.1
Liquid-side pressure P_f [Pa]	±0.5%
Liquid-side pressure ΔP_f [Pa]	±1.72%
Liquid-side volume flow rate G_f [m^3/s]	±0.5%
Heat capacity Q [W]	±2.26%
Liquid-side Reynolds number Re	±1.85%
Liquid-side heat transfer coefficient h_f [W/(m^2·°C)]	±11.2%
Liquid-side Nusselt number Nu_f	±11.4%
Liquid-side friction factor f_f	±3.49%

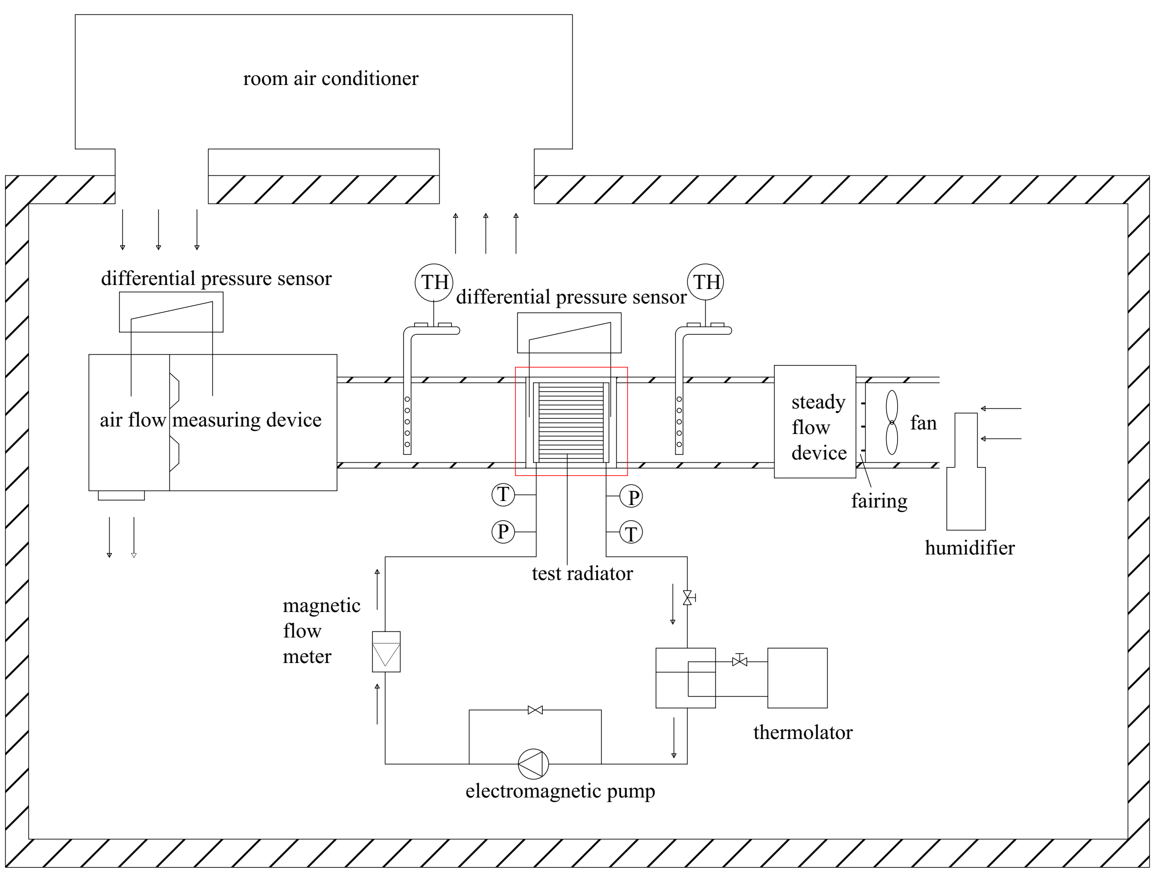

Fig. 1. Schematic of heat exchanger performance test facility.