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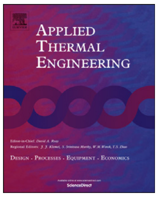

An experimental study of the characteristics of fluid flow and heat transfer in the multiport microchannel flat tube

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HIGHLIGHTS

- Multiport microchannel flat tubes with different sizes and geometries are investigated as test tube.
- The transition of six tubes occurs at $Re_{cr} = 1200-1600$.
- Aspect ratio has no correlation with the early laminar–turbulent transition.
- Entrance effect has significant impact on friction factors at the high Reynolds number.
- The roughness and entrance effect both can enhance heat transfer.

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ABSTRACT

This study aims to research on the flow and heat transfer characteristics of a flat aluminum extruded multiport tube using water as working fluid. This kind of tube is composed of numerous parallel of rectangular microchannels and is widely used in industry as heat transfer unit of heat exchanger. Six samples with hydraulic diameter ranging from 0.48 to 0.84 mm, aspect ratio varying from 0.45 to 0.88 and relative roughness ranging from 0.29% to 1.06% are carried on experimental investigation to test friction factor and Nusselt number. The test is performed with Reynolds number varied from 120 to 3750, covering the laminar, critical, and early transition zone. The experimental results show that the laminar–turbulent transition occurs at $Re_{cr} = 1200-1600$ respectively for six samples. For friction factor, entrance effect has a significant impact in turbulent region, while roughness seems to be negligible and no evidence can be found to indicate that aspect ratio has correlation with the early transition. For Nusselt number (convective heat transfer process), both roughness and entrance effect can enhance heat transfer. Roughness is more significantly effective at high Reynolds numbers, while the entrance effect is more effective in the laminar region.

1. Introduction

Energy is an increasing vital issue of everyday life with the development of economy and science. The proliferation of energy conversion and recovery measures, and the utilization of clean, new and renewable energy sources are the keys to solve the problems caused by energy such as environmental pollution and energy shortage. Heat exchanger, a device that allows heat transfer in a variety of ways, is a core component of many of the above processes. Hence, the heat exchangers have been widely applied in power generation, transportation, HVAC, electronics and manufacturing over the decades. Nowadays, the microchannel heat exchanger, which is demand for miniaturized, lightweight, compact, and high efficiency of heat transfer, becomes increasing necessary due to the increase of heat production, space limitation, and materials saving [1].

Many fundamental researches on the characteristic of single-phase fluid flow and heat transfer in the microchannel can be found in the published literature. Table 1 summarizes the experimental results of some studies and reports the ranges of the important microchannel fluid flow and heat transfer parameters. Because of the different experimental conditions, the results are not constant and it is found that there are many factors to influence the research result. Mala et al. [2] investigated the water flow through the fused silica and stainless steel microtube. The results indicated the material dependence of the flow behavior. Pfund et al. [3] measured the pressure drops for water flow in microchannels and calculated friction factors. Authors found that the confidence of

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Nomenclature

a	channel width, m
A	total wetted area, m^2
b	channel height, m
d	wall thickness of the tube, m
c_p	specific heat capacity, J/kg K
D_h	hydraulic diameter, m
e	wall thickness between channels, m
f	friction factor
G	mass flow rate, kg/s
h	heat transfer coefficient, W/m^2 K
K	roughness, m
L	tube length, m
MMFT	multiport microchannel flat tube
N	channels number
Nu	Nusselt number
Pe	perimeter, m
Pr	Prandtl number
ΔP	total pressure differential, Pa
ΔP_f	frictional pressure loss, Pa
ΔP_m	singular pressure loss, Pa
q	heat flux, W/m^2
Q	heat transfer rate gained by fluid, W
Re	Reynolds number
Re_{cr}	critical Reynolds number
Re^*	laminar-equivalent Reynolds number
T	temperature, °C
x	axial distance, m
x^*	dimensionless axial distance for the thermal entrance region
y	directly measured parameters
z	indirectly measured parameter

Greek symbols

α	aspect ratio ($0 < \alpha < 1$)
μ	dynamic viscosity, Pa s
ρ	mass density, kg/m^3
δ	uncertainty
λ	thermal conductivity, W/m K

Subscripts

app	apparent
f	fluid
in	inlet
out	outlet
w	wall

channel geometry and roughness is important factors in determining the friction factor for laminar flow. Garimella et al. [4] measured the effect of development flow on the Nusselt number of three different tube sizes and shapes. According to the geometry range studied, the effect of aspect ratio was not significant. Agostini et al. [5] studied the friction factor and heat transfer coefficient in a flat aluminum multiport extruded tube composed of 11 parallel rectangular channels with hydraulic diameter of 2.01 mm. It was found that heat transfer and frictional pressure loss are very close to the conventional tubes. Guo and Li [6] emphasized the discrepancy between experimental results and standard values due to the measurement errors might be misunderstood as caused by novel phenomena at microscales. And variations of the predominant factors influence on the relative importance of various phenomena on the flow and heat transfer. Rosa et al. [7] presented a review of the experimental and numerical results on single-phase heat transfer in microchannels. The importance of scaling effects (entrance effects, conjugate heat transfer, viscous heating, temperature dependent properties, surface roughness, rarefaction and compressibility effects) were also discussed. Zhou and Yao [8] studied the effect of roughness on liquid flow pressure drop and transition based on experimental data from the open literature. The results show that all the normalized data can be predicted within error of 15% using the original constricted flow model. Mirmanto

Table 1

Selected literature for single-phase liquid flow in microchannel.

Author	Year	Shape	Fluid	D_h (mm)	Re	Re_{cr}	Nu	N
Peng et al. [15]	1995	Rec	Water/methanol	0.31–0.75	200–4000	300–400	0.6–15	4–6
Peng et al. [16]	1996	Rec	Water–methanol	0.133–0.367	6–3500	200–700	0.3–40	Sin
Adams et al. [17]	1998	Cir	Water	0.102–1.09	2600–23,000	–	15–230	Sin
Mala et al. [2]	1999	Cir	Water	0.05–0.254	30–2200	300–900	–	Sin
Harms et al. [14]	1999	Rec	Water	1.923	1383–12,900	–	40.9–159	Sin
		Rec	Water	0.404	173–3169	≈1500	2.65–17.6	68
Pfund et al. [3]	2000	Rec	Water	0.128–0.521	60–3450	≈1700	–	18
Xu B. et al. [18]	2000	Rec	Water	0.03–0.344	20–4000	≈1500	–	Sin
Garimella et al. [4]	2001	Rec	Ethylene glycol	1.74/2.21/3.02	118–10,671	800–2000	5–60	Sin
Judy et al. [19]	2002	Rec/Cir	Water/methanol	0.015–0.15	8–2300	–	–	Sin
Warrier et al. [20]	2002	Rec	FC-84	0.75	–	≈1140	4–10	5
Agostini et al. [5]	2002	Rec	R134a	2.01	900–5500	≈2000	2–51	11
Lee et al. [21]	2005	Rec	Water	0.194–0.534	300–3500	1500–2000	6–35	10
Li et al. [22]	2006	Rec	Water	0.311–0.325	200–3267	1765–2315	–	Sin
Celata et al. [23]	2006	Cir	Water	0.12–0.528	50–3138	≈2300	2–30	Sin
Agostini et al. [24]	2006	Rec/Cir	Glycol–water	0.77–2.01	142–13,335	1400–2000	0.5–100	9
Celata et al. [25]	2007	Cir	Water	0.12–0.528	50–7025	≈2300	1–50	Sin
Caney et al. [26]	2007	Rec	Water	1.0	310–7780	≈2500	2–20	Sin
Jung et al. [27]	2008	Rec	Water	0.1–0.13	50–300	–	0.5–1.4	5
Mokrani et al. [28]	2009	Rec	Water	0.1–1	100–5000	2000–3000	8–50	Sin
Barlak et al. [29]	2011	Cir	Water	0.2–0.589	100–10,000	2000–2500	–	Sin
Mirmanto et al. [9]	2012	Rec	Water	0.438–0.635	100–7000	1000–2000	3–30	Sin
Farahani et al. [30]	2013	Rec	R1234ze(E)	1.45	100–8000	1500–1600	4–40	7