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WALL TEMPERATURE DISTRIBUTIONS OF GASEOUS FLOWS IN MICRO-TUBES WITH CONSTANT HEAT FLUX

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Experiments, Convective heat transfer, Vacuum chamber

ABSTRACT

Since the experimental study had been conducted by Tuckerman and Pease [1], microchannels has attracted significant attention as a component of compact and high-performance cooling devices. However, it is well known that the flow and heat transfer characteristics of gas flow through microchannels are different from those of of liquid flow due to the effects of compressibility, rarefaction and surface roughness. Therefore, in order to reveal the flow and heat transfer characteristics of microchannel gas flow, numerous studies have been undertaken [2]. In the case of microchennal gas flow at high speed, a large expansion occurs near the outlet and the pressure gradient along the length is not constant with a significant increase near the outlet [3]. This results in flow acceleration and an increase in gas velocity. Then, the gas temperature decreases near the outlet in adiabatic microchannel. The distributions of the wall temperature have similar trend with those of the gas temperature strongly depending on gas velocity.

Yang et al. [4] measured the surface temperature of stainless steel micro-tubes of D= 86, 308 and 920 μm using a non-contact liquid crystal thermography (LCT) temperature measurement method for avoiding the thermocouple wire thermal shunt effect. They reported that the conventional heat transfer correlation of laminar and turbulent flow could be well applied in the prediction of the fully developed gaseous flow heat transfer performance in microtubes. Yang et al. [5] investigated experimentally and numerically the convective heat transfer of nitrogen gas flow in commercial stainless steel micro-tubes of D= 170, 510 and 750 μm with constant heat flux wall. It is demonstrated that the specific correlations proposed for the prediction of the Nusselt number in micro-tubes fail in the presence of strong compressibility. There seems to be few experimental studies for obtaining heat transfer characteristics of gas flow in micro-tubes with constant heat

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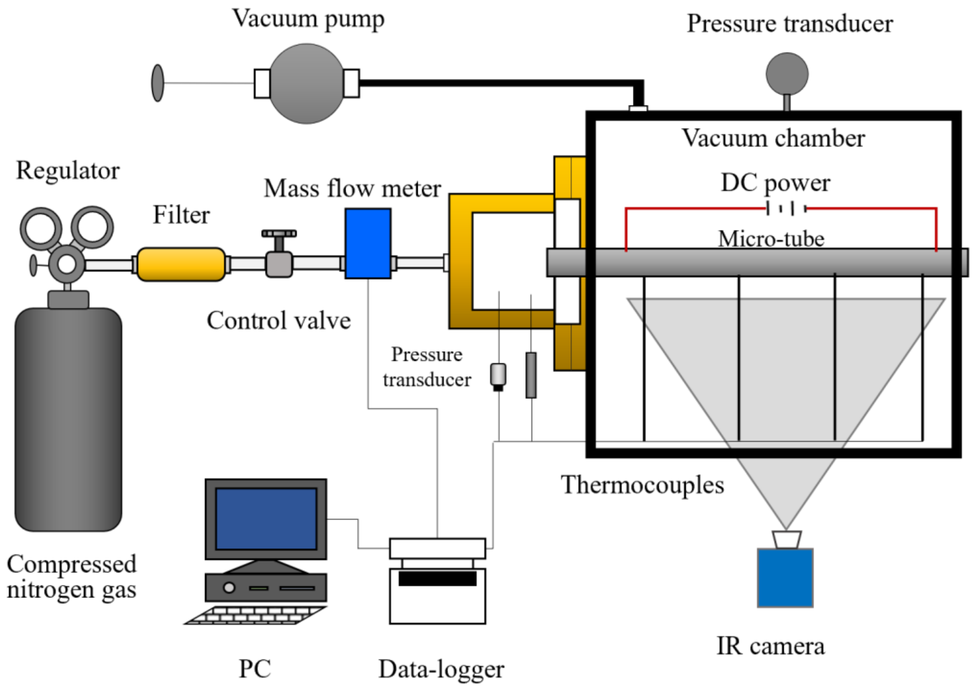


Figure 1: Schematic of experimental setup

heat flux are still unknown because of measurement limit. This is the motivation of the present experimental study to measure the wall temperatures of stainless steel microtubes with constant heat flux.

The experimental setup is shown in Fig. 1. A stainless steel micro-tube with D= 522.9 µm and L= 100 mm was tested in the present study. The tube inner diameter was measured by flowing water in the tube [3]. The test section was installed in a vacuum chamber to avoid the heat gain or loss by natural convection from outside of the test section. The chamber was evacuated by a vacuum pump in advance to maintain the inside pressure low. The stagnation temperature and pressure, T_{stg} and p_{stg}, were measured by setting a gauge pressure transducer (Krone KDM30) and a thermocouple (sheath Type-K) inserted into the chamber. The outer wall temperature was measured by four thermocouples (bare wire type-K, ϕ=50µm) are attached to the micro-tube outer wall at four locations along the length with a high conductivity epoxy. An infrared thermo-camera (FLIR Systems, FLIR C3) will be also used to measure the outer wall temperature. The micro-tube is heated by Joule effect by mean of a DC power supply (A&D Company, Limited, AD-8722D) in order to impose a constant heat flux along the micro-tube wall.

Nitrogen gas is used as the test fluid. The stagnation pressure at the inlet ranges from 130 to 650 kPa with 10 kPa, 25kPa or 50 kPa interval. The preliminary experiments where the wall temperature is measured by thermocouples were conducted before the test section is installed in a vacuum chamber. And the locally measured wall temperatures along the length by thermocouples are plotted in Fig. 2. These are results for a case of $\dot{q} = 5349\ \mathrm{W/m^2}$. In the case of slow flow ($p_{\mathrm{stg}} \leq 300$ kPa), the wall temperature increases linearly along the length depending on the constant heat flux but it levels off near the outlet. On the other hand, in the case of fast flow ($p_{\mathrm{stg}} > 300$ kPa). The wall temperature keeps constant or slightly decreases along the length due to the energy conversion into kinetic energy from thermal energy. The locally measured wall temperatures are also plotted in Fig. 3 (a) as a function of the stagnation pressure. And, the wall temperature measured for

$\dot{q} = 0$ W/m^2 are plotted in Fig. 3 (b). The measured wall temperatures of both $\dot{q} = 5349$ and $\dot{q} = 0$ W/m^2 nearly decrease with increase in p_{stg} except $140 \leq p_{\text{stg}} \leq 160$ for $\dot{q} = 0\ \text{W/m}^2$ because of the compressibility effect. In the range of $p_{\text{stg}} > 400$ kPa which is a region predicted to be choked flow, the wall temperature slightly decreases since Joule Thomson effect presented in actual situation is dominant. In the case of $\dot{q} = 0$ W/m^2 a temperature increase by the velocity decrease in transitional flow region can be seen. However, in the case of $\dot{q} = 5349$ W/m^2, the temperature increase cannot be seen since temperature change by constant heat flux on the wall is relatively large.

Average friction factors between the inlet and outlet for $\dot{q} = 0\ \text{W/m}^2$, inlet Mach numbers and outlet Mach numbers were also obtained and discussed. The wall temperatures measured in a vacuum chamber will be reported at the conference and also compared with those obtained in preliminary experiments and those of incompressible flow.

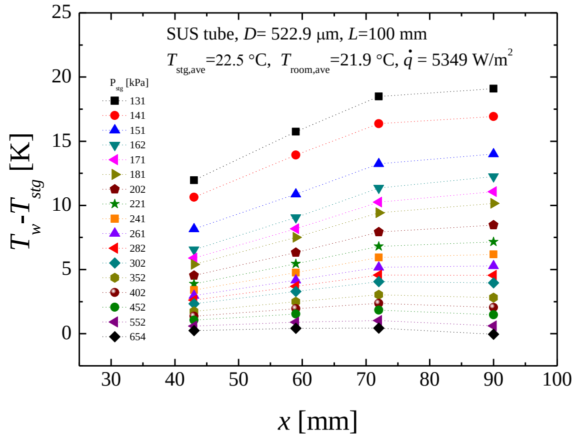
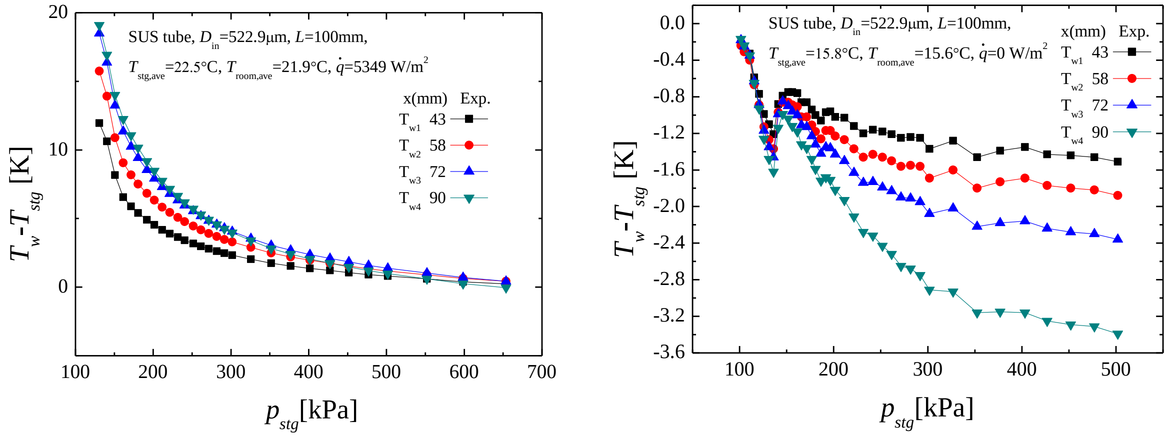


Figure 2: Wall temperatures on the micro-tube



(a) $\dot{q} = 5349$ W/m^2

(b) $\dot{q} = 0$ W/m^2

Figure 3: Wall temperatures as a function of p_{stg}

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