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EFFECT OF SURFACE ROUGHNESS ON LOCAL FRICTION FACTOR OF GAS FLOW THROUGH MICROTUBES

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ABSTRACT

During the last decades, microchannel flow and heat transfer have attracted an important research interest in micro electro mechanical systems (MEMS). Therefore, there is a great need for understanding of fluid flow and heat transfer characteristics in microchannels. It is well understood that gas flows in microchannels whose hydraulic diameters are higher than 10 μm are mainly affected by the combined effects of compressibility and surface roughness. Lorenzini et al. [1] investigated laminar, transitional and turbulent friction factors of nitrogen flows in smooth and rough microtubes. They obtained average friction factors between inlet and outlet within Re<15000 under the assumption of an isothermal flow. Murakami and Asako [2] conducted a numerical simulation to obtain the compressibility effect on the local friction factors of gas flow in microtubes. Kawashima and Asako [3] measured local pressure in a PEEK micro-tube with 514.4 μm in diameter and 50 mm in length to obtain the compressibility effect on friction factors since the inner surface of PEEK tube is smooth. The obtained friction factor are 12-20 % higher than the values predicted from the Blasius formula since the burrs of the pressure holes which were drilled on the PEEK micro-tube wall exist. Kawano et al. [4] experimentally investigated semi-local friction factors of gas flow through two microtubes, glass tube and fused silica tube. Their diameters were 399.9 and 531.2 μm. The influence of only the compressibility effect on flow characteristics was assessed since the inner surface of glass and fused silica tubes is smooth.

In the present study, the both effects of compressibility and surface roughness on local friction factors of nitrogen gas flow through microtubes discharged into the atmosphere experimentally investigated. The experiments were carried out with four stainless steel microtubes whose diameters are 129, 267, 355 and 520 μm. Two or three pressure tap holes of 50 μm on the microtube wall at intervals of 5~10mm were fabricated by Electrical Discharge Machining (EDM) to measure local pressures to determine the local values of Mach number, temperature and friction factor. The arithmetic mean height of the surface of the microtubes was measured with a 3D laser scanning confocal microscope for profilometry (Keyence VK-X260, Display resolution: 1 nm) to access the effect of surface roughness.

The stagnation pressure was selected in such a way that the flow is ranging up to $Re \approx 35000$. The flow in higher Reynolds number becomes a fully under-expanded flow at the microtube outlet. The

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result in the wide range of Reynolds number and Mach number were obtained including the choked flow. Both the Fanning and the Darcy friction factors were obtained under the assumption of both a Fanno flow (adiabatic wall) and an isothermal flow, respectively. The effect of temperature decreases in friction factors was investigated because the gas temperature steeply decreases due to energy conversion from thermal energy into kinetic energy in a high speed microtube gas flow. The obtained friction factors were compared with the empirical correlations of literatures on Moody's chart. Fanning friction factors, f_f which do not have acceleration loss for smaller diameter (D=124 and 267 μm) deviate from the Blasius correlation since the effect of surface roughness is relatively large (Fig. 1). The values of the measured surface roughness for D=267 and 520 μm are listed in Fig. 1 and those of D=124 and 355 μm will be measured by the presentation. The effect of surface roughness on friction factors of the present stainless steel tubes were also compared with that of equivalent sand grain surface roughness [5].

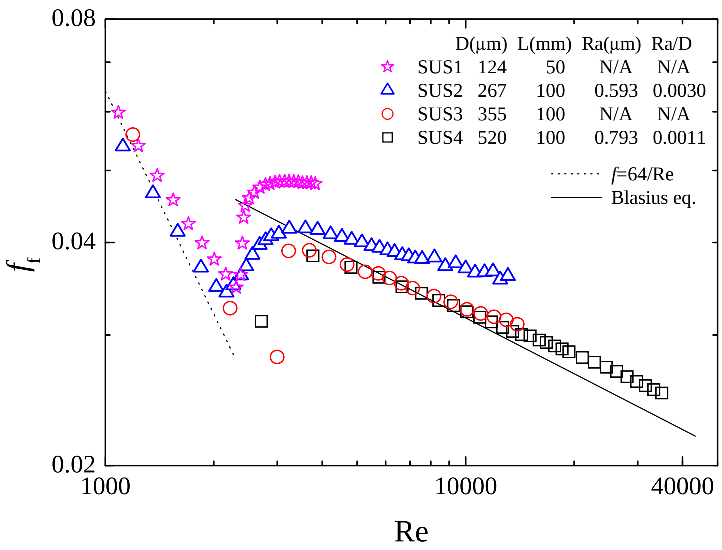

Figure 1: Friction factors on Moody’s chart

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References and Citations

[1] Lorenzini, M., Morini, G. L., & Salvigni, S. (2010). Laminar, transitional and turbulent frciton factors for gas flows in smooth and rough microtubes, *International Journal of Thermal Sciences*, 49, 248-255.

[2] Murakami, S., & Asako, Y. (2011). Local Pipe Friction Factor of Compressible Laminar or Turbulent Flow in Micro-Tubes, *9th International Conference on Nanochannels, Microchannels, and Minichannels*, ICNMM2011-58036.

[3] Kawashima, D., & Asako, Y. (2016). Measurement of quasi-local friction factor of gas flow in a micro-tube, *Proc IMechE Part C: J Mechanical Engineering Science*, 230 (5), 782-792.

[4] Kawano, T., Hong, C., Katanoda, H., & Asako, Y. (2017). Measurement of Semi-local Friction Factors of Gaseous Flow through Micro-tubes with Smooth surface, *6th International Symposium on Micro and Nano Technology*, TS7-2108.

[5] Schlichting, H. (1979). *Boundary-Layer Theory*, seventh edn. McGRAW-HILL