An Experimental Study for the Effects of Inner Surface Roughness and Heating on Friction Factors inside Horizontal Micro-Tubes

by

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Supervisor

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Abstract

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by Ng Wa San

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According to Krishnamoorthy *et al*. (2007), pressure drop measurements for horizontal micro-tubes under isothermal condition have been conducted by various researchers in recent years. From their literature review, it was shown that the friction factor in micro-tubes could unanimously be predicted by using macro-scale theory and that there is a need to investigate certain issues like (a) the effect of micro-tube diameter on the transition Reynolds number range and (b) the effect of the inner surface roughness on the friction factor and transition region. Regarding to the point (a), Ghajar *et al*. (2010) measured the pressure drop for a horizontal mini- and micro-tubes with various diameters in the transition region under isothermal condition. Their experimental results indicated the influence of the tube diameter on the friction factor profile and on the transition Reynolds number range. However, regarding to the point (b), the effect of roughness on friction factor profile and transition was still not fully understood. Moreover, only a few studies have investigated the effect of heating on friction factor in micro-tubes, especially, in the transition region.

Therefore, in this study, an experimental setup was built to measure pressure drop

for horizontal micro-tubes under the isothermal and uniform wall heat flux boundary conditions. Water was used as the test fluid and the test section were stainless steel tubes of the diameter ranging from 508μm to 2,000μm with various roughnesses. Form the measurements, the effect of roughness and heating on friction factor and transition region was clearly observed. For friction factor under isothermal condition, compared to the macro-tube, the micro-tube had a narrower transition region due to the roughness. Furthermore, the decrease of tube diameter induced a narrower transition range and basically delayed the start of transition. For friction factor under heating condition, the laminar and transition data were different form the isothermal case. Also, heating delayed the start of transition. The effect of heating was not seen on the turbulent region. For the isothermal and heating boundary conditions, when the tube diameter was ranging from 508μm to 750μm, the effect of roughness on the transition friction factors can be seen. Earlier transition was caused by larger inner surface roughness.

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GLOSSARY

c_p	specific heat of the test fluid evaluated at T_b, J/(kg·K)
C_f	fully developed friction factor coefficient (Fanning friction factor), ($=2 \cdot \tau_w / \rho \cdot V^2$), dimensionless
D_i	inside diameter of the test section (tube), m
D_o	outside diameter of the test section (tube), m
f	fully developed friction factor coefficient (Darcy friction factor), ($=8 \cdot \tau_w / \rho \cdot V^2$), dimensionless
h	fully developed peripheral heat transfer coefficient, W/(m^2·K)
k	thermal conductivity, W/(m^2·K) evaluated at T_b, W/(m·K)
L	length of the test section (tube), m
Nu	local average or fully developed peripheral Nusselt number ($= h \cdot D_i / k$), dimensionless Word.
Pr	local bulk Prandtl number ($=c_p \cdot \mu_b / k$), dimensionless
Ra	surface roughness, μm
Re	local bulk Reynolds number ($=\rho \cdot V \cdot D_i / \mu_b$), dimensionless
St	local average or fully developed peripheral Staton number [=Nu / (Pr·Re)], dimensionless
T_b	local bulk temperature of the test fluid, ℃
T_w	local wall temperature inside wall temperature, ℃
V	average velocity in the test section, m/s
X	local axial distance along the test section from the inlet, m
ΔP	pressure difference, Pa
μ	average absolute viscosity of the test fluid, Pa·s
μ_b	absolute viscosity of the test fluid evaluated at T_b, Pa·s
μ_w	absolute viscosity of the test fluid evaluated at T_w, Pa·s
ρ	density of the test fluid evaluated at T_b, kg/m^3
ε	surface roughness height, μm

τ_w wall shear stress, Pa

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