Experimental Investigation for the Forced and Mixed Convection Heat Transfer inside the Macro- and Mini-tubes


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Abstract

In the past studies, the effect of free convection on forced convection (i.e. mixed convection) can be observed in the laminar and lower transition regions of the macro-tube. However, the effect of free convection on heat transfer has not been well studied in the smaller diameter tubes such as the mini-tube and micro-tube. Therefore, an experimental setup was built for this study to measure the forced and mixed convection heat transfer for the horizontal macro- and mini-tubes under the uniform wall heat flux boundary condition. The experimental system was verified with the 4 mm macro-tube. Also two stainless steel mini-tubes (2 mm and 1.2 mm in inner diameters) were used as the test section. The experiments cover the range of Reynolds numbers from 800 to 8500. In the laminar region, the result showed that the buoyancy effect on heat transfer was present in the 4 mm and 2 mm tubes but the heat transfer inside the 1.2 mm tube was dominated by the forced convection. Although the transition for all tube diameters started at the similar critical Reynolds number, the transitional behavior of the macro-tube was different from those of the mini-tubes.

Keywords: heat transfer, forced and mixed convection, macro- and mini-tubes

Nomenclature

cp specific heat of the test fluid evaluated at T1, J/(kg·K)
Di inner diameter, mm
Do outer diameter, mm
g acceleration due to gravity, m/s²
Gr Grashof number [= g·β·ρ²·D3/(μb²). (Tω-Tb)/μb²], dimensionless
h fully developed peripheral heat transfer coefficient, W/(m²·K)
hb local peripheral heat transfer coefficient at the bottom of tube, W/(m²·K)
hl local peripheral heat transfer coefficient at the top of tube, W/(m²·K)
k thermal conductivity evaluated at Tb, W/(m·K)
L total length of the test section, mm
Lh heating length of the test section, mm
Nu local average or fully developed peripheral Nusselt number (= h·Di/k), dimensionless
Pr local bulk Prandtl number (= cp·μb/k), dimensionless
Re local bulk Reynolds number (=ρ·V·Di/μb), dimensionless
St local average or fully developed peripheral Stanton number (= Nu/(Pr·Re)), dimensionless
Tb local bulk temperature of the test fluid, ºC
Tw local inside wall temperature, ºC
V average velocity in the test section, m/s
x local axial distance along the test section from the inlet, m

Greek Symbols

β coefficient of thermal expansion of the test fluid evaluated at Tb, K⁻¹
μb absolute viscosity of the test fluid evaluated at Tb, Pa·s
μw absolute viscosity of the test fluid evaluated at Tw, Pa·s
ρ density of the test fluid evaluated at Tb, kg/m³

Subscripts

l laminar
t turbulent

1 Introduction

Due to rapid advancement in fabrication techniques, the miniaturization of devices and components is ever increasing in

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