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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 results 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

c_p	specific heat of the test fluid evaluated at T_b, J/(kg·K)
D_i	inner diameter, mm
D_o	outer diameter, mm
g	acceleration due to gravity, m/s^2
Gr	Grashof number [$= g \cdot \beta \cdot \rho^2 \cdot D_i^3 \cdot (T_w - T_b)/\mu_b^2$], dimensionless
h	fully developed peripheral heat transfer coefficient, W/(m^2·K)
h_b	local peripheral heat transfer coefficient at the bottom of tube, W/(m^2·K)
h_t	local peripheral heat transfer coefficient at the top of tube, W/(m^2·K)
k	thermal conductivity evaluated at T_b, W/(m·K)
L	total length of the test section, mm
L_t	heating length of the test section, mm
Nu	local average or fully developed peripheral Nusselt number ($= h \cdot D_i / k$), dimensionless
Pr	local bulk Prandtl number ($= c_p \cdot \mu_b / k$), dimensionless
Re	local bulk Reynolds number ($= \rho \cdot V \cdot D_i / \mu_b$), dimensionless
St	local average or fully developed peripheral Stanton number [$= Nu/(Pr \cdot Re)$], dimensionless
T_b	local bulk temperature of the test fluid, ºC
T_w	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 T_b, K^{-1}
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

Subscripts

l	laminar
t	turbulent

1 Introduction

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