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Experimental Study of the Ultrasonic Effect on Heat Transfer inside a Horizontal Mini-Tube in the Laminar Region

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Abstract

Ultrasound has been widely used in the drying, welding, cleaning, chemical, and heat transfer processes. Moreover, in recent years there has been an increased interest in the application of ultrasound for heat transfer enhancement in the field of heat transfer. However, a few papers investigated the effect of ultrasound on heat transfer inside the horizontal tube. Therefore, the objective of this experimental study is to investigate the influence of ultrasound on the heat transfer inside the horizontal tube in the laminar region. In this study, the stainless steel test tube with the diameter of 4 mm was used as the test section under the uniform wall heat flux boundary condition. The entrance and fully developed regions heat transfer coefficients were analyzed. The Reynolds number ranged from 600 to 3000. A series of experiments with the different numbers of ultrasonic heads and the different locations of the heads placed on the tube were conducted. The results showed that a substantial heat transfer enhancement by ultrasound was observed in the laminar region. Based on the combinations of different number and position of ultrasonic heads, two ultrasonic heads were observed to give a better heat transfer enhancement in the entrance and fully developed regions.

Keywords: Horizontal mini-tube, Ultrasound, Heat transfer enhancement, Laminar region

Nomenclature

c_p	specific heat of the test fluid evaluated at T_b, J/(kg·K)
D_i	inside diameter of the test section (tube), 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	local peripheral heat transfer coefficient, W/(m^2 K)
k	thermal conductivity, W/(m^2 K) evaluated at T_b, W/(m^2 K)
L	length of the test section (tube), m
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

1 Introduction

Heat transfer enhancement is an important topic in the area of thermal engineering. For the tube flow, the heat transfer can be increased by the passive or active methods [1]. Passive method consists of roughing the tube inner surface, inserting the swirl-flow devices into the tube, and adding the solid-particles into the fluid. Traditional active method is the application of mechanical aids, vibration, and electrostatic fields on the tube. Tam and his coworkers [2] applied the passive method, i.e. the micro-fins, to increase the heat transfer inside the macro-tube of 14.8 mm. Although the increase of heat transfer was obvious in