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Heat transfer enhancement in a tube with combined conical-nozzle inserts and swirl generator

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Abstract

The enhancements of heat transfer characteristics in a uniform heat flux circular tube fitted with conical nozzles and swirl generator are experimentally investigated. In this research, the conical nozzles, assumed as a turbulator/reverse flow generator, are placed in a model pipe line through which air as working fluid is passed. Three different pitch ratios (PR) of conical-nozzle arrangements in the test tube are introduced with PR = 2.0, 4.0 and 7.0 in each run. In addition, the snail is also employed to provide swirling flow at the inlet of the test tube. It is found that each application of the conical nozzle and the snail can help to increase considerably the heat transfer rate over that of the plain tube by about 278% and 206%, respectively. The use of the conical nozzle in common with the snail leads to a maximum heat transfer rate that is up by 316%. Correlation equations for Nusselt number, friction factor and performance evaluation criteria to assess the real benefits in using the turbulators and swirl generator of the enhanced tube are determined.

Keywords: Heat transfer enhancement; Friction; Swirl flow; Re-circulation, Reverse flow; Turbulator; Conical nozzle; Snail

1. Introduction

Conventional sources of energy have been depleting at an alarming rate, which makes future sustainable development of energy use very difficult. Thus, researches on seeking ways to reduce the size and cost of heat exchangers have been conducted. Heat transfer enhancement technology has been developed and widely applied to heat exchanger applications over the past decades; for example, for refrigeration, automotives, process industry, solar water heater etc., because the reduction in overall thermal resistance can lead to a smaller heat exchanger. To date, there have been a large number of attempts to reduce the size and costs of heat exchangers [1–3]. In general, methods to enhance heat transfer can be divided into two groups. One is the passive method without stimulation by external power, such as a surface coating, rough surfaces, extended surfaces, swirl flow devices, convoluted (twisted) tube, additives for liquids and gases etc.. The other is the active

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Nomenclature

A	heat transfer area, m^2
$C_{p,a}$	specific heat capacity of air, $J\,kg^{-1}\,K^{-1}$
D	inner diameter of test tube, m
D_o	outer diameter of test tube, m
f	friction factor
h_p	heat transfer coefficient of plain tube, $W\,m^{-2}\,K^{-1}$
h_t	heat transfer coefficient of turbulator, $W\,m^{-2}\,K^{-1}$
I	current, amp
k	thermal conductivity of air, $W\,m^{-1}\,K^{-1}$
L	length of test section, m
l	pitch length of conical-nozzle arrangement, m
$\dot{m}$	mass flow rate, $kg\,s^{-1}$
μ	dynamic viscosity, $Ns\,m^{-2}$
Nu	Nusselt number
η_e	enhancement efficiency
Pr	Prandtl number
ΔP	pressure drop, Pa
PRs	pitch ratio, (l/D)
Q_{air}	heat transfer rate of hot air, W
Q_{conv}	heat transfer rate of wall, W
Re	Reynolds number
T_o	temperature of outlet air, K
T_i	temperature of inlet air, K
T_w	local temperature of wall, K
$\tilde{T}_w$	mean temperature of wall, K
T_b	mean temperature of air, K
t	thickness of test tube, m
U	averaged axial velocity inside test section, $m\,s^{-1}$
V	voltage, V
$\dot{V}$	volume flow rate of hot air, $m^3\,s^{-1}$
v	kinematic viscosity, $m^2\,s^{-1}$

method, which requires extra external power sources, for example, mechanical aids, swirl flow-turbulator devices, flow-induced vibration, surface-fluid vibration, injection and suction of the fluid, jet impingement and use of electrostatic fields.

The reverse flow device or the turbulator is widely employed in heat transfer engineering applications. The reverse flow is sometimes called "re-circulation flow". The effects of reverse flow and boundary layer disruption (dissipation) are to enhance the heat transfer coefficient and momentum transfers. The reverse flow with high turbulent flow can improve convection to the tube wall by increasing the effective axial Reynolds number, decreasing the cross-section flow area and increasing the mean velocity and temperature gradient. It can help to produce higher heat fluxes and momentum transfer due to the large effective driving potential force but also higher pressure drop. The strength of the reverse flow and the reattached position are the main interest in many heat transfer applications, such as heat exchangers, combustion chambers, gas turbine blades and electronic devices. Yakut and Sahin [4] used conical-ring turbulators placed inside the tube to produce reverse/turbulent flows in each module of the conical rings. Therefore, heat transfer was improved along the tube wall. In their experimental study, the level of the reverse flow (re-circulation flow) was generated from the separation and reattachment of a boundary layer from different pitch lengths between the modules.