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Heat transfer in a circular tube fitted with free-spacing snail entry and conical-nozzle turbulators ☆

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Abstract

The paper presents the effect of a free-spacing snail entry together with conical-nozzle turbulators on turbulent heat transfer and friction characteristics in a uniform heat-flux tube. The insertions of the conical or converging nozzle (C-nozzle) with different pitch ratios (PR) in common with the free-space snail entry are examined in a Reynolds number range from 8000 to 18000. A substantial augmentation of heat transfer for using the C-nozzles and snail entrance is expected by a strong influence from nozzle-induced reverse/re-circulation motion and snail-produced vortex/swirl motion for high Reynolds number. The experimental result shows a considerable increase in friction factor and heat transfer over the plain tube under the same operation conditions. Over the range investigated, the Nusselt numbers for employing both the enhancement devices with PR = 2.0, 4.0 and 7.0 are found to be higher than that for the plain tube around 315%, 300% and 285% respectively. The results obtained are correlated in the form of Nusselt number as a function of Reynolds number, Prandtl number and pitch ratio. For performance comparison at equal pumping power, both the enhancement devices with the smallest pitch ratio perform the best, especially at low Reynolds number. The present results are also compared with correlations obtained from similar enhancement devices but without free-spacing entry.

Keywords: Heat transfer augmentation; Swirl flow; Re-circulation/reverse flow; Turbulator; Snail entry; Enhancement device

1. Introduction

The development of high-performance thermal systems has still stimulated considerable interest in methods to improve heat transfer. The conventional heat exchangers are improved by means of various augmentation techniques with emphasis on many types of surface enhancements. Augmented surfaces can create one or more combinations of the following conditions that are favorable for the increase in heat transfer rate with an undesirable rise of friction: 1) disruption of the development of boundary layer and increase of the turbulence intensity, 2) increase in heat transfer area, and 3) generation of swirling/rotating and/or secondary flows. For the effective performance evaluation of passive augmentation methods for example twisted tape, wire coil, and extended surface which are used in force convection situations, both the heat transfer and flow friction characteristics of the enhancement technique must be known [1–3]. The convection heat transfer along

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Nomenclature

A	Heat transfer surface area (m^2)
$C_{p,a}$	Specific heat of air (J/kg K)
D	Inner diameter of tube (m)
D_o	Outer diameter of tube (m)
f	Friction factor
h	Average heat transfer coefficient (W/m^2 K)
I	Current (amp)
k	Thermal conductivity of air, (W/m K)
L	Length of test tube (m)
l	Pitch length (m)
$\dot{m}$	Mass flow rate (kg/s)
Nu	Nusselt number
ΔP	Pressure drop (Pa)
PR	Pitch ratio, $l/D=1+S$
Pr	Prandtl number
Q_a	Heat transfer absorbed by air (W)
Q_{conv}	Convective heat transfer (W)
Re	Reynolds number
Re_t	Reynolds number of turbulator
Re_p	Reynolds number of plain tube
s	Space length (m)
S	Space ratio, s/D
t	Thickness of tube, m
T_b	Bulk temperature (°C)
T_i	Inlet temperature (°C)
T_o	Outlet temperature (°C)
T_w	Wall temperature (°C)
$\tilde{T}_w$	Mean wall temperature (°C)
U	Average axial velocity (m/s)
V	Voltage (volt)
$\dot{V}$	Volume flow rate (m^3/s)

Greek symbols

η_e	Enhancement efficiency
ρ	Density (kg/m^3)
μ	Dynamic viscosity (kg/s m)

the tube wall can be improved significantly by introducing the reverse/re-circulation flow with a view to increasing the effective axial Reynolds number, decreasing the cross-sectional area of flow, and increasing the mean velocity and temperature gradient. This is because the reverse flow can induce the higher heat fluxes and momentum transfer due to the large effective driving potential force but also higher pressure drop. The strength of 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] experimentally studied the heat transfer and friction characteristics in a uniform heat flux fitted with conical-ring turbulators used to provide reverse/turbulent flows in each module of the conical rings. Therefore, significant improvement of heat transfer along the tube wall was reported. The enhancements of heat transfer in a uniform heat-flux circular tube fitted with conical-nozzles and swirl generator were also experimentally investigated by Promvonge and Eiamsa-ard [5]. In their research, the conical-nozzles were placed in a test tube with three different pitch ratios of conical-nozzles, apart from the snail mounted at the tube inlet. The use of the conical-nozzle in conjunction with