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Studies on heat transfer and friction factor characteristics of laminar flow through a circular tube fitted with right and left helical screw-tape inserts

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Abstract

Experimental investigation on heat transfer and friction factor characteristics of circular tube fitted with right-left helical screw inserts of equal length, and unequal length of different twist ratio have been presented. The experimental data obtained were compared with those obtained from plain tube published data. The heat transfer coefficient enhancement for right-left helical screw inserts is higher than that for straight helical twist for a given twist ratio. The effect of right-left helical twist length on heat transfer and friction factor were presented. The empirical relation for Nusselt number, friction relating Reynolds number, twist ratio and right-left distance were formed and found to fit the experimental data within 10% and 20% for Nusselt number and friction factor, respectively. Performance evaluation analysis has been made and the maximum performance ratio of 2.85 and 2.97, respectively were obtained for 300 R and 300 L, and 400 R and 200 L type inserts.
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Keywords: Augmentation; Laminar flow; Right-left helical screw inserts; Twist ratio; Heat transfer

1. Introduction

The heat transfer augmentation or intensification is the technique of improving the performance of heat transfer system resulting in reducing the size and cost of the heat exchanger. Heat transfer enhancement technology is being very widely adapted in heat exchanger used for various process applications like refrigeration, automotives, process industry, chemical industry etc. Bergles [1,2] presented a comprehensive survey on heat transfer enhancement by various techniques. Among many techniques investigated for augmentation of heat transfer rates inside circular tubes, tube fitted with full length twisted tape inserts (also called as swirl flow device) has been shown to be very effective, due to imparting of helical path to the flow.

Helical screw-tape swirl flow generators shown in Fig. 1 is a modified form of a twisted tape wound on a single rod gives single way smooth direction of flow like screw motion. In the earlier paper [3] heat transfer and friction factor characteristics of laminar flow through a circular tube fitted with straight helical screw-tape inserts has been reported. The present paper reports the heat transfer and friction factor characteristics of right-left helical screw inserts of equal length, and unequal length of different twist ratio under laminar flow with the water as working fluid.

2. Technical details of helical screw-tape inserts

The geometrical configuration of helical screw-tape inserts is shown in Fig. 1. The helical screw-tape inserts

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Nomenclature

A_i	inside surface area of test section area, m^2
A_o	outside surface area of test section area, m^2
C_p	specific heat at constant pressure, KJ/kg K
D_i	inside diameter of test section, mm
D_o	outside diameter of test section, mm
f	friction factor, dimensionless
f_{plain}	friction factor for plain tube, dimensionless
f_{twist}	friction factor for twist, dimensionless
h_i	average convective heat transfer coefficient, W/m^2 K
k	thermal conductivity of fluid, W/m K
k_w	thermal conductivity of the tube wall, W/m K
L	length of the test section, m
L_t	left twist length, m
Nu	Nusselt number, dimensionless $Nu = h_iD_i/k$
Nu_{plain}	Nusselt number for plain tube, dimensionless
Nu_{twist}	Nusselt number for twist, dimensionless
Q	heat transfer rate, W
Pr	Prandtl number dimensionless $Pr = C_p\mu/k$
R	resistance of the heating element, Ω (ς)
R_t	right twist length, m
Re	Reynolds number based on internal diameter of the tube, dimensionless
T_f	average of fluid temperature in the test section, K
T_{in}	inlet bulk temperature of fluid, K
T_{out}	outlet bulk temperature of fluid, K
T_{wo}	average wall surface temperature outside test section, K
u_m	bulk average fluid velocity, m/s
U_o	over all heat transfer coefficient, W/m^2 K
V	voltage output from the Auto-transformer, V
Y	twist ratio (length of one full twist (360°) diameter of the twist), dimensionless

Greek symbols

ρ	density of fluid, kg/m^3
μ	viscosity of fluid, N s/m^2
ΔP	pressure drop of fluid, N/m^2

of different twist ratio was made by winding uniformly a strip of 8.5 mm width over a 8 mm rod, and coated with chromium by electroplating to prevent corrosion. The twist ratio 'Y' defined as the ratio of length of one full twist (360°) to diameter of the twist is varied from 2.93 to 4.89. The right-left helical inserts were formed by joining 300 mm length of right twist and 300 mm length of left twist alternatively, and joining 400 mm length of right twist and 200 mm length of left twist alternatively as shown in Fig. 1.

3. Experimental set-up and procedure

The experimental set-up and procedure for the conduct of experiment is same as that described in earlier paper [3] except that after plain tube run right-left helical twist of equal and unequal length cited above were inserted and experiments were performed.

4. Pressure drop calculation

The pressure drop was determined from the differences in the level of manometer fluid. The fully developed friction factor was calculated from the following equation:

$$f = (D_i/L)(\Delta P/2\rho u_m^2) \tag{1}$$

where ΔP is the pressure drop over length L.

5. Heat transfer calculation

The heat transfer rate in the test section was calculated using [4]

$$Q = V^2/R = mC_p(T_{out} - T_{in}) = U_oA_o(T_{wo} - T_f) \tag{2}$$

where

$$1/(U_oA_o) = 1/(h_iA_i) + \ln(D_o/D_i)/(2\pi k_w L) \tag{3}$$

The internal convective heat transfer coefficient, h_i was determined by combining Eqs. (2) and (3).

The thermal equilibrium test showed that the heat supplied by electrical winding in the test section was 8–10% larger than the heat absorbed by the fluid. This was caused by thermal loss from the test section. The average value of heat transfer rate obtained by heat supplied by electrical winding, and heat absorbed by the fluid was taken for internal convective heat transfer coefficient calculation.

The Nusselt number was calculated using equation

$$Nu = h_iD_i/k \tag{4}$$

All the fluid thermophysical properties were determined at the average of the inlet and outlet bulk temperatures, T_f.

Experimental uncertainty was calculated following Coleman and Steele method [5] and ANSI/ASME standard [6]. The uncertainties associated with the experimental data are calculated on the basis 95% confidence level. The measurement uncertainties used in the method are as follows: bulk fluid temperature and wall temperatures ±0.1 °C, fluid flow rate ±2%, and fluid properties ±2% The uncertainty calculation showed that maximum of ±6%, ±5%, and ±8% for Reynolds number, friction factor and Nusselt number, respectively.

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