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Heat transfer and fluid flow characteristics of heat exchanger tube with multiple twisted tapes and solid rings inserts

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ABSTRACT

Heat transfer and fluid flow characteristic of a roughened tube is investigated for constant heat flux. The inserts were employed for the swirl flow generation in the test section through the tube. Pitch ratios (l/D) = 1 and 2 of the solid ring tubular (SRT) and twist ratios (y/W) = 2, 3 and 4 of the twisted tapes (TT) are introduced into the core flow. The Reynolds number covered in the range of 6300–22500 for co-twist arrangements for the turbulent flow of air in the tested heat exchanger tube. The study reveals that the Nusselt number, friction factor and thermal performance factor of the integrated SRT and TT are in the range of 107–293, 0.93–0.99 and 1.46–1.61, respectively. The highest thermal performance factor in the order of 1.61 over smooth tube heat exchanger was obtained for the integrated device consisting of the SRT with l/D = 1.0 and y/W = 2. The quadruple co-twisted tape insert provides the maximum Nusselt number, friction factor, thermal performance factor. The correlations for the Nusselt number, friction factor and thermal performance factor of the tubes with combined devices were also developed in terms of flow and geometrical parameters.

1. Introduction

Heat exchanger is the device that accommodates in the wide ranges of temperature for the transfer of heat from one place to another. The Heat exchangers are commonly used over a wide range of applications from engineering devices to house hold appliances. In the present scenario across the globe the cost of energy saving and miniature engineering systems, motivates industry to employ energy-saving methods as possible in their installations. The rate of heat transfer in heat exchanger is solely depended on the temperature gradient available across the working fluids at any prospective location, and that temperature gradient varies over the length of heat exchanger. The heat transfer enhancement in heat exchangers can broadly be categorized into the active method that requires extra external power sources such as fluid vibration, injection and suction of the fluid, jet impingement and electrostatic fields and the other are the unassertive method that requires no other power source. The devices incorporated in the category of passive heat transfer enhancement [1] are surface coating, rough surfaces, turbulent/swirl flow devices, extended surfaces, etc. Numerous researches reported as passive heat transfer enhancement technique with turbulators as an effective technique for performance enhancement of heat exchangers. Sarada et al. [2] used varying width twisted tape inserts for enhancement of heat transfer. Chokphoemphun et al. [3] used multiple twisted tapes and found increase in both Nu and f with an increase in value of N, while with counter twisted tape arrangements, it tends to decrease. Eiamsa-ard et al. [4] used circular-rings and twisted tapes and found that the heat transfer rate increases with increasing Reynolds number and decreasing pitch/twist ratio. Promvonge [5] used wire coil and twisted tape turbulator and compared it with a smooth tube at a constant pumping power. A double fold increase in heat transfer performance was obtained for low Reynolds number. Eiamsa-ard et al. [6] used short and full length twisted tapes and found thermal performance enhancement above unity only for the full-length tape insert at low Reynolds number. The maximum enhancement in thermal performance of the short length twisted tapes are found of the order of around 0.95, 0.98 and 1.00 for LR = 0.29, 0.43 and 0.57, respectively. Bas and Ozceyhan [7] used single twisted tape and it was observed that the Nusselt number increases with decrease of clearance ratio (c/D) and twist ratio (y/D). Matani and Dahake [8] used single twisted tape heat exchanger and found that the co swirl generated considerably enhanced the heat transfer rate and thermal performance over smooth tube heat exchanger. Bhuiya et al. [9] used the double counter twisted tape and such twisted tape offered a significant enhancement in heat transfer, friction factor as well as thermal enhancement efficiency

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Nomenclature

A_O	Cross section area of orifice (mm)
C_d	Coefficient of discharge for orifice
C_P	Specific heat of air at constant pressure (J/Kg K)
D	Outer diameter of pipe (mm)
D_i	Internal diameter of pipe (mm)
d_i	Internal diameter of solid ring (mm)
d_o	Outer diameter of solid ring (mm)
DTT	Double twisted tape
f	Friction factor
f_s	Friction factor of smooth tube
h	Convective heat transfer coefficient (W/m^2 K)
K	Thermal conductivity of air (W/m K)
L	Length of the pipe (mm)
$\dot{m}$	Mass flow rate of fluid (Kg/s)
Nu	Nusselt number
Nu_s	Nusselt number of smooth tube
ΔP	Pressure drop across test section (Pa)
ΔP_0	Pressure drop across the orifice plate (Pa)
Pr	Prandtl number
QTT	Quadruple twisted tape
Re	Reynolds number
STT	Single twisted tape
TTT	Triple twisted tape
T_a	Ambient temperature (K)
T_i	Fluid inlet temperature (K)
T_o	Fluid outlet temperature (K)
T_w	Local wall temperature (°C)
W	Width of twisted tape (mm)
y	Length of twist (mm)
σ	Stefan–Boltzmann constant (W/m^2 K^4)
ρ_{air}	Density of air (Kg/m^3)
μ	Dynamic viscosity (Kg/ms)

compared with the plain tube. Burse [10] work focused on experimental investigation of heat transfer and friction factor characteristics of horizontal circular pipe by the means of twisted tape inserts with air as the working fluid. Nusselt number and friction factor obtained experimentally were validated against those obtained from theoretical correlations. Promvonge and Eiamsa-ard [11] used conical ring and twisted tape and found increased in Nusselt number and enhancement efficiency value of the order of 4–10% and 4–8%, respectively higher than with the conical ring alone. Eiamsa-ard et al. [12] carried experimental investigation with the delta-winglet twisted tape and the study revealed that the mean Nusselt number and mean friction factor for the tube increased with decrease in twist ratio (y/w) and increasing depth of wing cut ratio (DR). Eiamsa-ard et al. [13] used coil wire and twisted tape insert in the tube. A significant enhancement in the thermal performance is observed for configured arrangement over smooth tube. Promvonge [14] used conical ring arrays as insert and found an increase in both Nusselt number and friction factor with decrease in the diameter ratio. Eiamsa-ard et al. [15] used different type arrangement of twisted tape and found the maximum heat transfer improvement in the full length dual twisted tapes. Eiamsa-ard and Pongjet [16] used twisted tape with serrated edge inserts and found that the Nusselt number increases to the rise in depth ratio but decrease with raising the width ratio. Ferroni et al. [17] used short length and full length twisted tapes and study reveals that short length tapes yields pressure drops at least 50% lower than the full length tapes. Chang et al. [18] used broken twisted tapes and found significant improvement in the performances of the tubes fitted with the broken twisted tape. Similarly Nanan et al. [19] used perforated helical twisted tape, Thianpong et al. [20] used twisted ring and Kongkaitpaiboon and co-workers [21,22] used circular ring and perforated conical ring as insert geometry in their study. So, according to previous work it is found that a number of studies are carried out in the field of heat transfer enhancement. Geometries used by different researchers mainly focused on core fluid disturbance or surface modification of heat exchanger tube. In the literature review above, many investigations are almost focused on the use of single, double and triple twisted tapes, apart from the modified twisted-tape while the effect of the tape number, co-twist arrangements have rarely been reported. Both core fluid disturbance and surface modification gave significant result for heat transfer enhancement.

Hence, in the present work combined form of core fluid disturbance and surface modification approach has been studied. Therefore, the utilization of double, triple and quadruple twisted-tapes with solid rings in various forms of co-twist arrangements is offered as an enhancement device in the present work. As according to literature, among core fluid disturbance device, twisted tape showed good result among all. Hence the effects of multiple twisted tape with different geometrical parameters with circular ring on heat transfer and friction characteristics is investigated in the present study.

2. Experimental investigation

Experimental facility mainly comprised of inlet section also called as calming section, test section, heating arrangement and air supplied system (blower). Inlet section is 2.5 m long, and its main purpose is to allow fully developed flow to enter into the test setup which comprises of heating arrangement followed by insulation at the outer surface of tube. To measure the temperature at the tube wall 12 T-type thermocouples are placed in the drilled grooves on tube wall such that the thermocouples are just located near to the inner surface of the tube wall, in order to sense inner wall temperature properly. The temperature of inlet and exit of the flow stream is measured by thermocouples placed near the inlet and exit positions of test section. At exit flow strainer is places for proper mixing of exit fluid and at exit three thermocouples are placed such that average temperature of all the three are taken as fluid exit temperature. The wall and fluid temperature were measured by the help of data logger, which is attached to computer with lab view software. For measuring pressure drop across the test section; digital micro manometer is used, which is attached to taps placed at inlet and exit of test section. The test section is followed by flow arrangements, which comprise of a blower with 2HP (horse power), 3Φ power supplies and in between blower and test section, flow measurement devices are attached. The flow measurement device comprises of orifice plate, U-tube manometer filled with water as manometric fluid and next to blower, flow control valve is attached to control

Table 1
Geometry and range of parameters.

Details	Dimensions
Length of galvanized iron pipe	6000 mm
Length of test section	1400 mm
Inner diameter of pipe	68 mm
Outer diameter of pipe	72 mm
Twist ratios (TR = y/W)	2, 3, 4
Pitch ratios (PR = l/D)	1, 2
Multiple twisted tape (N)	1, 2, 3,4
Reynolds number (Re)	6000–23000