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Experimental Investigation on Turbulent Flow Heat Transfer in a Horizontal Circular Pipe using Coil and Twisted Tape Inserts

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Abstract: *In this work, experimental investigation is carried out to understand influence of twisted tape and internal coil on heat transfer characteristics in a circular tube. The work focuses on experimental investigation of heat transfer & friction factor characteristics of horizontal circular pipe by the means of inserts, with air as working fluid. Nusselt number & friction factor obtained experimentally were validated against those obtained from theoretical correlations. The twisted tapes used are of three different twist ratios such as 1.78, 2.32 and 2.77. Also a coil is inserted tightly in a pipe. Initially experiment was carried out for plain tube at constant wall heat flux & different mass flow rates of air. Secondly experiment was carried out with insertions in a tube for the same working conditions as that of plain tube. The experimental results obtained were compared with those obtained from plain tube.*
Keywords: *Enhancement, heat transfer, coil and twisted tape inserts, turbulent flow, pressure drop*

I. Introduction

Conventional resources of energy are depleting at an alarming rate, which makes future sustainable development of energy use very difficult. As a result, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. Heat transfer augmentation techniques are generally classified into three categories namely: active techniques, passive techniques and compound techniques. Passive heat transfer techniques (ex: tube inserts) do not require any direct input of external power. Hence many researchers preferred passive heat transfer enhancement techniques for their simplicity and applicability for many applications. Tube inserts present some advantages over other enhancement techniques, such as they can be installed in existing smooth tube that exchanger, and they maintain the mechanical strength of the smooth tube. Their installation is easy and cost is low. It relatively easy to take out for cleaning operations too.

In the present work the experimental investigation of the augmentation of turbulent flow heat transfer in a horizontal tube is done by means of twisted tape and coil inserts with air as the working fluid. Experiment was carried out for plain tube with/without inserts at constant wall heat flux and different mass flow rates, to investigate the friction factor and heat transfer characteristics of air in an externally heated horizontal tube. The present work has been carried out with turbulent flow (Re number range of 8,000- 20,000) as most of the flow problems in industrial heat exchangers involve turbulent flow region.

II. Review Of Work Carried Out

In the recent years, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. This can be seen from the exponential increase in world technical literature published in heat transfer augmentation devices, growing patents and hundreds of manufacturers offering products ranging from enhanced tubes to entire thermal systems incorporating enhancement technology. Energy and materials saving considerations, space considerations as well as economic incentives have led to the increased efforts aimed at producing more efficient heat exchanger equipment through the augmentation of heat transfer. Among many techniques investigated for augmentation of heat transfer rates inside circular tubes, a wide range of inserts have been utilized, particularly when turbulent flow is considered. The inserts studied included twisted tape inserts, coil wire inserts, brush inserts, mesh inserts, strip inserts, etc.

Dewan et al. [1] has reviewed progress with passive augmentation techniques in the recent past & will be useful to designers implementing passive augmentation techniques in heat exchange. Twisted tapes, wire coils, ribs, fins, dimples etc. are the most commonly used. In the present paper emphasis is given to works with dealing with twisted tapes & wire coils because according to recent studies these are known to be economic heat transfer augmentation tools. Kumar et al. [2] has mainly focused on the twisted tape heat transfer enhancement & it's design modification towards the enhancement of heat transfer & saving pumping power. Rahman et al. [3] studied experimental investigation of heat transfer enhancement through inner grooved copper tubes in a heat exchanger. A series of test were conducted to determine the condensation & evaporation performance of the inner grooved copper tubes namely B3-42 & B16-46 where R-22 was used as refrigerant. The straight & horizontal test section of the apparatus with a length of 3.67m was heated or cooled by water circulated in surrounding annulus. For both condensation & evaporation tests, the heat transfer coefficient & pressure drop are found to increase as the mass flux increases.

Shrivastava et al. [4] has been studied the enhancement in heat transfer for the forced convection condensation of R-22 saturated vapour inside a tube in presence of twisted tape inserts. The test condenser is constituted by four test sections conducted in series. Three twisted tape inserts with the twist ratio 15,9 & 6 were put, one by one, in the test condenser. The insert with twist ratio y of 6 gave the best performance & enhanced average heat transfer coefficient by 25 percent as compared to the plain flow. Sapali et al. [5] experimentally investigated two phase heat transfer coefficients & pressure drops of R-404A in a smooth & micro fin tube. The present experiment is performed for different condensing temperatures. The experimental results from both smooth & micro-fin tubes show that the average heat transfer coefficient & pressure drop increases with mass flux but decreases with increasing condensing temperature. The average heat transfer coefficient is 30-210% higher for micro-fin tube than that of smooth tube, with moderate increase in pressure drop ranging from 10-55%. New correlations based on the data gathered during the experimentation for predicting condensation heat transfer coefficients are proposed for wide range of practical applications.

Sarada et al. [6] has done experimental investigation of the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. In order to reduce excessive pressure drops associated with full width twisted tape inserts, with less corresponding reduction in heat transfer coefficient, reduced width twisted tapes are used. Experiments were carried out for plain tube with/without twisted tape insert at constant wall heat flux & different mass flow rates. Both heat transfer coefficient & pressure drop are calculated & the results are compared with those of plain tube. Shrirao et al. [7] focused on experimental investigation of heat transfer & friction factor characteristics of horizontal circular pipe using internal threads with air as the working fluid. The experimental data obtained were compared with those obtained from plain horizontal pipe. The effects of internal threads of varying depth on heat transfer & friction factor were presented. Based on the same pumping power consumption, the pipe with internal threads possesses the highest performance factors for the turbulent flow.

III. Experimental Work

3.1 Experimental Setup

The test apparatus is an open air flow loop as shown in Fig.1,that consists of blower unit fitted with a pipe, which is connected to the test section. Bend heater encloses the test section to a length 50 cm to cause electric heating. Input to heater is given through dimmer stat having range of 0-230 Volts. Six thermocouples T2, T3, T4, T5, T6, T7 are embedded on the walls of the test tube and two thermocouples T1 and T8 are placed in the air stream. One at the entrance and the other at the exit of the test section to measure the temperatures of flowing air. The type of thermocouples used are Copper constantan. Display unit consists of Voltmeter, Ammeter and Temperature indicator which shows thermocouples output through selector switch. The circuit was designed for a load voltage of 0-260V; with a maximum current of 2A.

Difference in the levels of manometer fluid represents the variations in the flow rate of air. The velocity of air flowing in the tube is measured with the help of orifice plate and the water manometer fitted on board. The pipe system consists a valve, which controls the airflow rate through it. The diameter of the orifice is 1.4 cm and coefficient of discharge is 0.64.

Pressure drop across test section is measured by connecting pressure tapings at each end of test section to U-tube differential manometer. The outer surface of the test section was well insulated to minimize heat loss to surrounding.

3.2 Procedure

The test section is assembled in test bracket and checked for air leakage. The blower was switched on to let a predetermined rate of air flow through the pipe. A constant heat flux is applied to the test section by adjusting the dimmerstat. Thermocouples T2 to T7 were fixed on the test surface and thermocouples T1 and T8 were fixed inside the pipe. The readings of the thermocouples were observed every 5 minutes until the steady state condition was achieved.

The experiment was performed for different mass flow rates of air. The mass flow rates considered for the constant heat input 35 Watt in terms of water level difference in U-tube water manometer are 8cm, 16cm, 24cm and 32cm. Initially the experiment was carried out for plain tube. Then the experiment was carried out for different insert combinations such as Coil, Coil with twisted tape of twist ratio 1.78 insert, Coil with twisted tape of twist ratio 2.32 insert, Coil with twisted tape of twist ratio 2.77 insert alternately for the same flow conditions.

Different types of inserts used are shown in Fig.2 and Fig.3.The twisted tape inserts are made of aluminum strips of different twist ratios such as 1.78, 2.32 and 2.77. The width of twisted tapes used are19 mm. Each insert was taken and inserted into test section axially through one end. It is taken care that the strip doesn't scratch the inner side of test section and get deformed. The coils cross section is circular of 3 mm diameter and it's material is copper. It is tightly inserted in a plain tube. After insertion of coil in the tube, it's inner diameter is 21mm.The fluid properties were calculated as the average between the inlet and outlet bulk temperature.

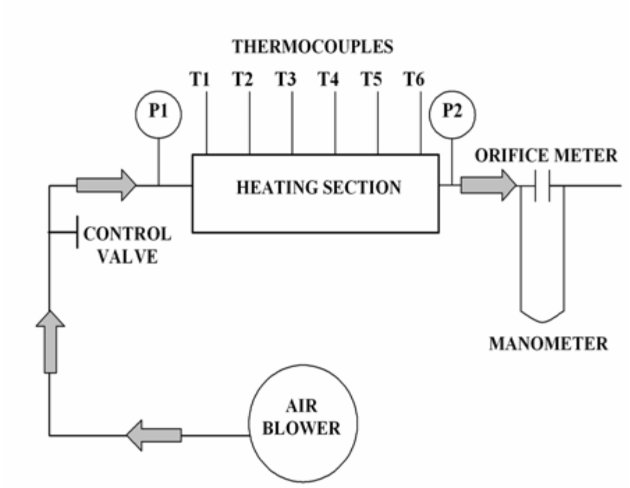

Fig. 1: Schematic diagram of Experimental setup

Fig. 2: Photograph of Twisted tape inserts

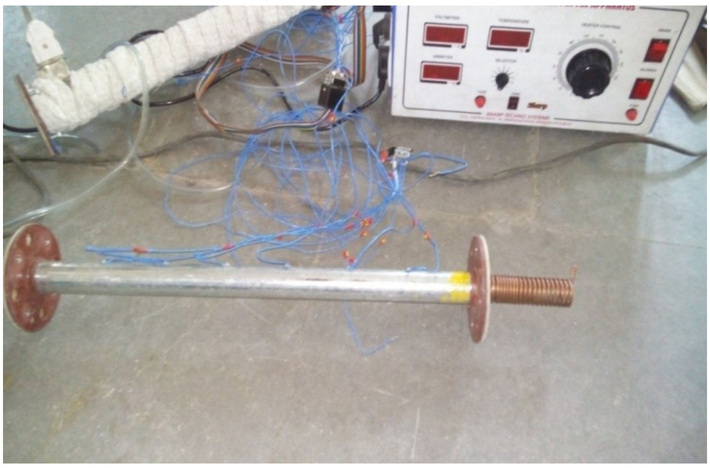

Fig. 3: Photograph of Coil inserts

3.3 Data Reduction

The data reduction of the measured results is summarized in the following procedures:

$$T_s = \frac{T2 + T3 + T4 + T5 + T6 + T7}{6} \quad (1)$$

$$T_b = \frac{T1 + T2}{2} \quad (2)$$

$$h_a = \frac{\rho_w h_w}{\rho_a} \quad (3)$$

$$q = \frac{C_d A_i A_o \sqrt{2gh_a}}{\sqrt{{A_i}^2 - {A_o}^2}} \quad (4)$$

$$\dot{m} = q \times \rho_a \quad (5)$$

$$Q = \dot{m} \times C_p \times (T8 - T1) \quad (6)$$

$$Q_r = \sigma \times A \times \varepsilon_C \times \left({T_s}^4 - {T_b}^4\right) \quad (7)$$

$$h = \frac{Q}{A \times (T_s - T_b)} \quad (8)$$

$$Nu = \frac{h \times D_i}{k} \quad (9)$$

(To calculate Nu while using inserts, D_h instead of D_i is used)

$$Nu_{the} = 0.023 \times Re^{0.8} \times Pr^{0.4} \quad (10)$$

$$U = \frac{q}{A_i} \quad (11)$$

$$Re = \frac{U \times D_i}{\nu} \quad (12)$$

(To calculate Re while using inserts, D_h instead of D_i is used)

$$f = \frac{\Delta P}{\frac{L \times \rho_a \times U^2}{2 \times D_i}} \quad (13)$$

$$f_{the} = 0.079 \times Re^{-0.25} \quad (14)$$

$$\eta = \frac{\frac{Nu_i}{Nu}}{\left(\frac{f_i}{f}\right)^{\frac{1}{3}}} \quad (15)$$

IV. Validation Test

The Nusselt number and friction factor determined from experimental data are compared with the values obtained from the correlations of Dittus- Boelter for the Nusselt number and Blasius correlation for the friction factor. Comparison between present experimental work and standard correlations for Nusselt number and friction factor turbulent internal flow is presented in Fig.4 and Fig.5 respectively. The results of present work reasonably agree within ± 22.73 for Nusselt number. From Fig.5 friction factor is observed to reduce with increase in Reynolds number for plain tube.

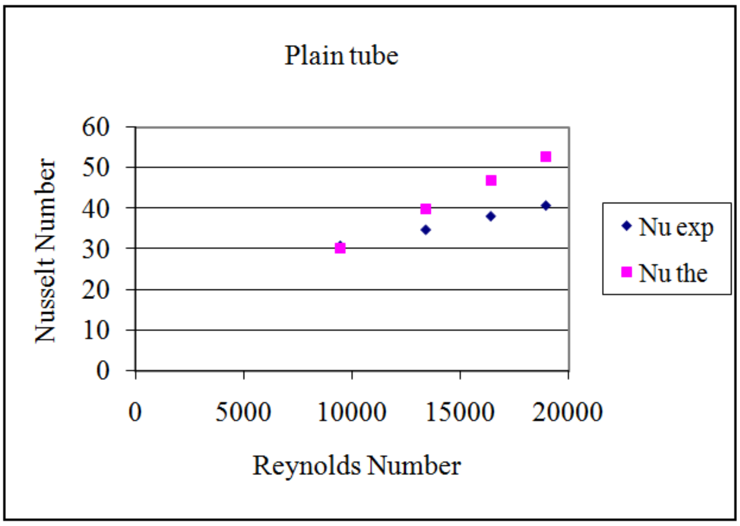

Fig.4: Comparison of Nusselt number with Reynolds number

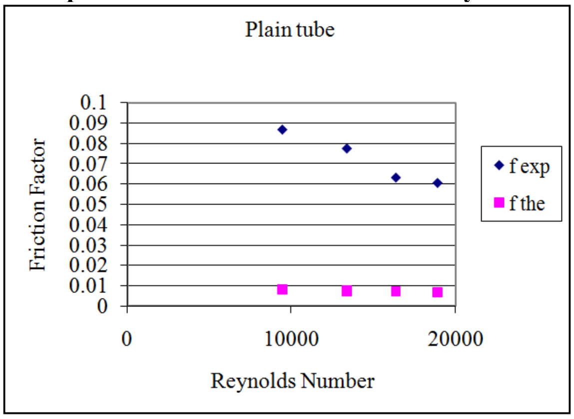

Fig. 5: Variation of friction factor with Reynolds number

V. Results And Discussion

In the present work, experimental investigation on turbulent flow heat transfer enhancement for air inside the horizontal tube in the presence of inserts such as coil & twisted tape of different twist ratio are carried out.Fig.6 shows the variation of Nusselt number with Reynolds number for all inserts in comparison to plain tube. Nusselt number increased with increase in Reynolds number as shown in Fig.6. It is observed that twisted tape of twist ratio 1.78 with coil, yielded the highest value of Nusselt number .This may be due to better turbulence created on air side in the presence of twisted tape of twist ratio 1.78 with coil, which increases the heat carrying capacity of air that led to increase of Nusselt number.

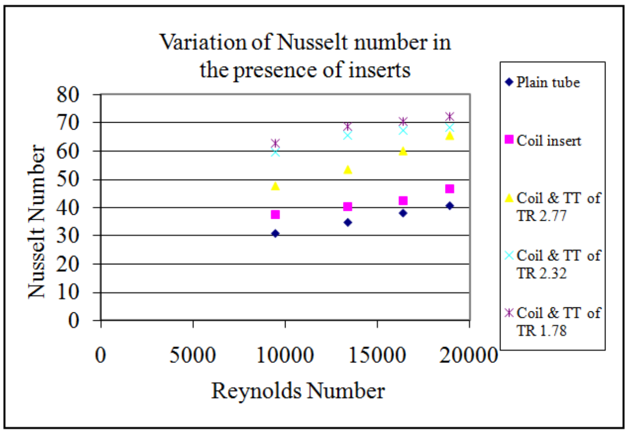

Fig. 6: Comparison of Experimental Nusselt Number with Reynolds Number

Fig.7 shows the variation of friction factor with Reynolds number for all inserts in comparison to plain tube. It is seen that the value of friction factor decreases with increasing Reynolds number in all cases. Friction factor also observed to be highest for twisted tape of twist ratio 1.78 with coil insert. This may be due to highest obstruction caused to air flow in the presence of these inserts.

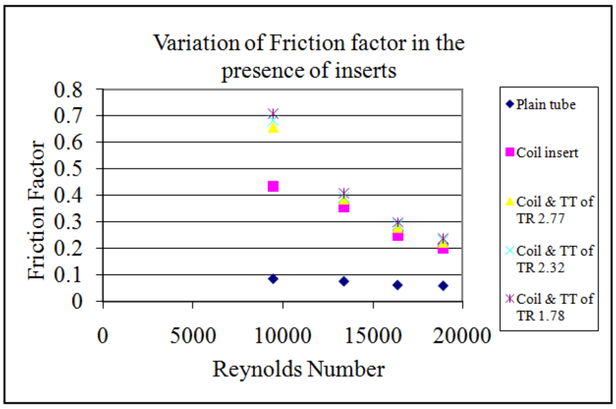

Fig. 7: Comparison of Experimental Friction Factor with Reynolds Number

The overall enhancement ratio is used to determine the quality of enhancement technique. It's value is observed to be highest for twisted tape of twist ratio 1.78 with coil insert. The maximum overall enhancement ratios are 1.1299, 1.0673, 1.0433, 0.7691 for TT of TR 1.78 with coil, TT of TR 2.32 with coil, TT of TR 2.77 with coil and coil insert respectively. In general, thermal performance of all inserts gets improved as the flow rate is increased. At higher Reynolds number, thermal performance is more, this is due to more expenditure required to propel the air through pipe. Based on our experimental investigation, it is observed that the Overall enhancement ratio shows highest values for TT of TR 1.78 with coil. This may be due to better turbulence given to air by this insert, which increased the contact of air with tube wall that led to enhancement of heat transfer rates.

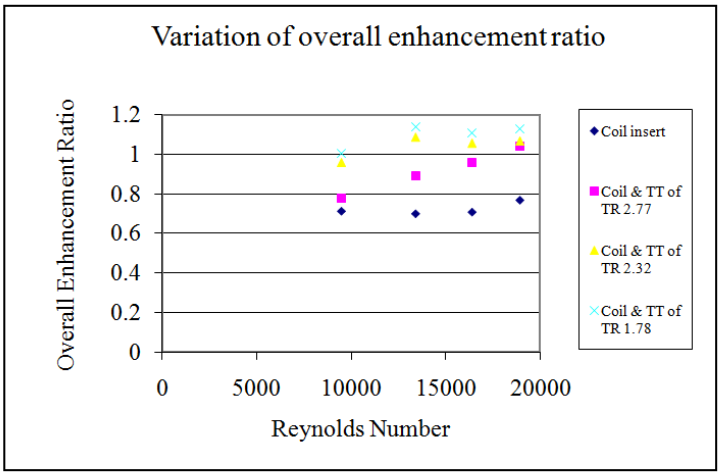

Fig.8: Variation of overall enhancement ratio with Reynolds number

VI. Conclusion

The study presents an experimental investigation of Coil & Twisted tape inserts to enhance the rate of heat transfer in a horizontal circular tube with inside diameter 28 mm with air as working fluid. The Reynolds number varied from 8000 to 20,000. The effects of parameters such as Twisted Ratio & Reynolds number on the heat transfer & overall enhancement ratio are studied.

Experimental investigations were performed to investigate the Friction Factor & heat transfer characteristics of air in an externally heated horizontal tube fitted with inserts such as Twisted Tape & Coil in comparison to plain tube. Twisted Tapes of three different Twist Ratios were used which are 2.77, 2.32 & 1.78 Twist Ratio. Also a coil is inserted into the plain tube. The study presents an combination two types of inserts, coil & twisted tape in a circular pipe. The experimental data obtained for each pipe design were compared with those obtained from plain tube data for the same flow conditions.

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Nomenclature

A	Convective heat transfer area ($\pi D_i L$), (m^2)
A_0	Area of orifice, (m2)
A_i	Test section inner tube area ($\pi D_i^2/4$), (m^2)
C_p	Specific heat of air, (J/kg K)
q	Air discharge through test section, (m^3/sec)
D_h	Hydraulic diameter (4A/P), (m)
D_i	Inner diameter of test section, (m)
d_o	Diameter of Orifice
H	Pitch, (m)
w	Width of tape insert,(m)
H/D_i	Twist ratio
H/w	Modified twist ratio
f_{the}	Friction factor (theoretical) for plain tube
f	Friction factor (experimental) for plain tube
f_i	Friction factor (experimental) obtained using inserts
h	Experimental convective heat transfer coefficient, (W/m^2K)
h_w	Manometer level difference,(m)
h_a	Equivalent height of air column, (m)
k	Thermal conductivity, (W/mK)
$\dot{m}$	Mass flow rate of air, (kg/sec)
Nu_i	Nusselt number (experimental) with inserts, (hD_h/k)
Nu	Nusselt number (experimental) for plain tube, (hD_i/k)
Nu_{the}	Nusselt number (theoretical) for plain tube
Pr	Prandtl number
ΔP	Pressure drop across the test section, (Pa)
Q	Heat transferred to air by convection
Q_r	Heat transferred to air by radiation, (W)
Re	Reynolds number, (UDi/ ν)
T1,T8	Air temperatures at inlet and outlet, (°C)
T2, T3, T4, T5, T6, T7 -	Tube wall temperatures, (°C)
T_s	Average Test surface temperature, (°C)
T_b	Bulk temperature of air, (°C)
U	Air velocity through test section, (q/A_i), (m/sec)

Greek symbols

ν	Kinematic viscosity of air, (m^2/sec)
η	Over all enhancement ratio
ρ_w	Density of water, (kg/m^3)
ρ_a	Density of air,(kg/m^3)
ε_C	Emissivity of copper
σ	Stefan- Boltzmann's constant

Abbreviations

TT	Twisted Tape
TR	Twist Ratio
b	Bulk mean
s	Surface
exp	Experimental
a	Air

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