Experimental Investigation of Heat Transfer Enhancement in Circular Tube Inserted with Twisted Tape by Forced Convection

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ABSTRACT
The present work shows the result obtained from experimental investigation of heat transfer enhancement in circular tube inserted with twisted tape by forced convection in horizontal tube at different velocity and different set of twisted tape, air as working fluid. The experiments were conducted on circular tube inserted with different sets of twisted tapes of diameter 33mm and length 400mm are inserted in the entire length of the tube in the orthogonal direction. Theoretical and experimental heat transfer coefficient are calculated, the heat transfer coefficient, nusselt number, pressure drop and friction factor data obtained is compared with the data obtained from a plain circular tube. The twist ratio is (12, 6, 4).

Keywords— heat transfer co-efficient, velocity, twisted tape, pressure drop.

1. INTRODUCTION

The heat transfer coefficients are generally low for laminar flow in plain tubes. The heat transfer rate can be improved by introducing a disturbance in the fluid flow, which can be achieved by inserted with the twisted tape in circular tube. At present the twisted-tape insert is widely used in various industries.

Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the convective heat transfer.

Heat transfer is a science that studies the energy transfer between two bodies due to temperature difference. Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion.

Convective heat transfer may be categorized into two forms according to the nature of flow:
1. Natural or free convection
2. Forced convection.

1.1 FREE OR NATURAL CONVECTION HEAT TRANSFER:
In natural or free convection, the fluid motion is driven by density differences associated with temperature changes generated by heating or cooling. In other words, fluid flow is induced by buoyancy forces. Thus the heat transfer itself generates the flow which conveys energy away from the point at which the transfer occurs.

Figure 1.1: Natural convection

Consider a hot object exposed to cold air. The temperature of the outside of the object will drop (as a result of heat transfer with cold air), and the temperature of adjacent air to the object will rise.

Consequently, the object is surrounded with a thin layer of warmer air and heat will be transferred from this layer to the outer layers of air. The temperature of the air adjacent to the hot object is higher, thus its density is lower. As a result, the heated air rises. This movement is called the natural convection current.

1.2 FORCED CONVECTION HEAT TRANSFER:
It is a mechanism, or type of transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.). It should be considered as
one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently.

Heat transfer by forced convection generally makes use of a fan, blower, or pump to provide high-velocity fluid (gas or liquid). The high-velocity fluid results in a decreased thermal resistance across the boundary layer from the fluid to the heated surface. This, in turn, increases the amount of heat that is carried away by the fluid.

**Mechanism of Forced convection:**

Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate). The rate of convection heat transfer is expressed by Newton’s law of cooling:

\[ q_{conv} = h(T_s - T_\infty) \, (W/m^2) \]  
\[ Q_{conv} = h A_s (T_s - T_\infty) \, (W) \]  

The convection heat transfer co-efficient \( h \) strongly depends on the fluid properties and roughness of the solid surface, and the type of the fluid flow (laminar or turbulent). It is assumed that the velocity of the fluid is zero at the wall, this assumption is called non-slip condition. As a result, the heat transfer from the solid surface to the fluid layer adjacent to the surface is by pure conduction, since the fluid is motionless.

**1.3 PRINCIPAL PARAMETERS:**

Some of the common dimensionless numbers are used in the convection heat transfer are:

**Nusselt number:**

Nusselt number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer.

\[ Nu = \frac{h d}{k} \]  

The larger the Nusselt number, the more effective the convection. \( Nu = 1 \) for a fluid layer represents heat transfer across the layer by pure conduction.

**Prandtl number:**

It is the ratio of molecular diffusivity of momentum to the molecular diffusivity of heat at about the same rate. The Prandtl numbers of gases are about 1. Heat diffuses very quickly in liquid metals (\( Pr << 1 \)) and very slowly in oils (\( Pr >> 1 \)) relative to momentum.

\[ Pr = \frac{\nu}{\alpha} = \frac{\mu C_p}{k} \]  

**Reynolds number:**

It is the ratio of inertia force to the viscous force.

\[ Re = \frac{\rho V D}{\mu} \]  

At large Reynolds numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces, and thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid. At small Reynolds numbers, however, the viscous forces are large enough to overcome the inertia forces and to keep the fluid “in line.” Thus the flow is laminar in nature.

**1.4 Temperature steady state**

It is important to ensure the steady state of an any temperature to ensure the effective results with the time, during the conduction of experiment it is necessary to reach the steady state with the time. This motivates to produce the proper result.

## II. METHODOLOGY

### 2.1 Specifications of the Specimens:-

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of test pipe (L)</td>
<td>400mm</td>
</tr>
<tr>
<td>Outer dia of the tube</td>
<td>36mm</td>
</tr>
<tr>
<td>Inner dia of the tube (D)</td>
<td>34mm</td>
</tr>
<tr>
<td>Orifice dia (d)</td>
<td>26mm</td>
</tr>
<tr>
<td>Material used</td>
<td>Mild steel</td>
</tr>
<tr>
<td>Number of twisted tape used</td>
<td>3</td>
</tr>
<tr>
<td>Full length twisted tape</td>
<td>Single twist</td>
</tr>
<tr>
<td>Full length twisted tape</td>
<td>Double twist</td>
</tr>
<tr>
<td>Full length twisted tape</td>
<td>Triple twist</td>
</tr>
<tr>
<td>Width of the twisted tape</td>
<td>33mm</td>
</tr>
<tr>
<td>Length of the twisted tape</td>
<td>400mm</td>
</tr>
<tr>
<td>Thickness of twisted tape</td>
<td>1.2mm</td>
</tr>
</tbody>
</table>

Table 2.1 specification of test specimen:

### 2.2 Fabricated Test Specimen:-
Fig 2.1 Different sets of twisted tape inserted in circular tube (Twist ratio y=12, 6, 4.)

2.3 Experimental setup

The experiments were carried out in an open-loop experimental facility as shown in Fig. The loop consisted of a 7.5 kW blower, orifice meter to measure the flow rate, and the heat transfer test section. The steel test tube has a length of $L = 400$ mm, with 34 mm inner diameter ($D$), 36 mm outer diameter ($D_o$). The tube was heated by electrical heaters a uniform heat flux boundary condition. The outer surface of the test tube was well insulated to minimize convective heat loss to surroundings, and necessary precautions were taken to prevent leakages from the system. The inner and outer temperatures of the bulk air were measured at certain points with the Chromel-constant thermocouples. Five thermocouples were tapped on the surface of the tube and the thermocouples were placed along the tube to measure the temperature variation, which was found to be negligible, And another thermocouple is placed at the exit of the tube to measure the outlet temperature of the air which is carried out by the cold air through the different sets of twisted tape inside.

### III. PRIOR APPROACH

Supply is given to the blower motor and the valve is opened slightly. A heat input of 40w is given to the nichrome heating wire wound on the test section by adjusting the dimmer stat. Thermocouples 2 to 5 are fixed on the test surface and thermocouples 1 to 6 are fixed inside the pipe. Thermocouples used for experimentation are J-type with an accuracy ±0.2%. The readings of the thermocouples are observed every 5 minutes until they show constant values. Under steady state condition, the readings of all the six thermocouples are recorded. The experiment is repeated for different openings of the valve, thus varying the airflow rate. The fluid properties were calculated as the average between the inlet and the outlet bulk temperature. It took 110 minutes to reach steady state conditions. Experiment was carried out at constant heat flux conditions and constant heat input of 40w at different mass flow rates. Initially the experiment is carried out without any insert (plain tube experiment). The working fluid air flows through the pipe section with least resistance. The experiment is carried out in similar fashion with straight tape inserts, with twisted tape inserts with twist ratios (pitch/diameter) 3, 4 and 5 for widths of 26, 22, 18, 14 and 10 mm. the inserts are made of aluminum. The mass flow rates considered for the constant heat input of 40 w in terms of water level difference in U-tube water manometer are 2 inch, 3 inch, 4 inch and 5 inches (air mass flow rate varying from 0.0033 to 0.0055 kg/sec).

### IV. OUR APPROACH

The method used for determining the heat transfer coefficient is to supply a known heat input to the heating coil and measure the temperature attained by the test model. Before undertaking the experiments an uncertainty analysis was performed to determine the effect of each of the parameters involved on the uncertainty in the heat transfer co-efficient values. The following procedure is followed in conducting experiments.

**Fig.4 Schematic Representation of Experimental Setup**

The experiments consist of an air blower to blow air through a tube. In that tube inserted a mild steel twisted tape. A valve is provided to control the air flow rate. A test section has been provided in the straight portion considerably away from the bend so that at test section the flow is fully developed. A flow straightened is provided. The test section has an electrical heater which is insulated...
to reduce the heat losses to the atmosphere. The test section is provided with 5 thermocouples at different axial locations (T2, T3, T4, T5 and T6) to measure the variation of the tube surface temperature along the test section. Inlet and outlet air temperature is measured by providing two more thermocouples at the inlet and the exit of the test section. Voltmeter and ammeter is provided to measure the rate of heat input. Air flow rate through the test section is measured by means of orifice meter.

RESULT AND DISCUSSION

4.1 Effect of Reynolds number on heat transfer coefficient:

![fig 4.1 heat transfer coefficient v/s Reynolds number]

The different twisted ratios of twisted tape are inserted in the circular tube. It is observed from the above figures that the heat transfer coefficient gradually increases in a inserted of twisted tape in circular tube with respect to plain circular tube. From the figure heat transfer coefficient increases with increasing the Reynolds number.

4.2 Effect of Reynolds number v/s Nusselt number:

![fig 4.2: Nusselt number v/s Reynolds number]

Figure shows nusselt number v/s Reynolds number, the nusselt number increases gradually in inserted twisted tape in circular tube with respect to plain circular tube in constant heat input. From the figure nusselt number increases with increasing the Reynolds number.

4.3 Effect of Reynolds number v/s pressure drop:

![fig 4.3: pressure drop v/s Reynolds number]

The above figure shows the variation of Reynolds number on pressure drop for a constant heat input of Q. The graph plotted above is for all the 3 specimens inserted in plain circular pipe. It is observed from the above figure that the pressure drop increases with the increase in the Reynolds number. And it shows that specimens with increase in twisted tape ratio pressure drop also increases slightly. Comparison of pressure drop for 3 specimens and the plain pipe is shown in graph above. It is observed that, plain pipe having lesser pressure drop than the 3 specimens for all heat inputs, due to no restriction for the flow of air through the pipe, whereas in the pipe with increasing number twisted ratio of internal inserted twisted tape air flow rate decreases which leads to increase in pressure drop.

4.4 Effect of Reynolds number V/S friction factor:

![fig 4.4: friction factor v/s Reynolds number]

The above figure shows the variation of Reynolds number on friction factor for a constant heat input of Q. The graph plotted above is for all the 3 specimens having different twist tape ratio inserted in plain circular pipe. It is observed from the above figure that the friction factor decreases with the increase in the Reynolds number. And it shows that specimens with increase the twist ratio (γ=12,6,4), friction factor resembles almost equal for all
the specimens. Comparison of friction factor for 3 specimens and the plain pipe is shown in graph above. It is observed that, plain pipe having lesser friction factor than the 3 specimens for all heat inputs, due to the smoothness of the surface inside the plain pipe whereas internal inserted twisted tape in the pipe acts as a obstacles for the flow of air which leads to higher friction factor.

V. CONCLUSION

Experimental investigations of heat transfer coefficient, Nusselt number pressure drop and friction factor of a plain circular tube and a circular tube with different set of twisted tape insert inside are described in the present report. The conclusions can be drawn as follows:
1. The heat transfer coefficient increases for a test tube with different set of twisted tape inserts inside than those for plain tube this is due to the fact that there is increase in the surface area of the tube provided by the different set of twisted tape, which increases the turbulence of air.
2. The friction factor increases for a test tube with inserted different set of twisted tape than the plain tube, because in the test tube with inserted different set of twisted tape turbulent or swirl flow is generated and different set of twisted tape resists the flow of air.
3. The enhancement of Nusselt number is higher in the case of tube with inserted different set of twisted tape, than plain tube because of the extended surface and high turbulence and higher Reynolds number.

REFERENCES