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Heat Transfer Enhancement Using a Rotating Twisted Tape Insert

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The secondary flow (swirl flow) is generated by twisted tape which promotes greater mixing and high heat transfer coefficients. Till now numerous researches have been done on twisted tape design to obtain an optimal solution. However, most of the research was done using a stationary twisted tube. This study uses a rotating twisted tape insert to observe the effect on heat transfer coefficient, heat transfer rate and heat enhancement efficiency. A physical model of the experimental setup was designed, built and instrumented for temperature measurements. The volume flow rate of fluid was varied from 8 liters per minute to 16 liters per minute and the rotation of twisted tape was varied from 0 RPM to 600 RPM. Experiments have been conducted by varying combination of the rotation and volume flow rate. The effects of relevant parameters experimental setup are investigated. The result that has been achieved in the research was impressive and encouraging.

Field of Research: Mechanical Engineering

Keywords: Twisted tape; RPM; Volume flow rate; Heat transfer coefficient.

1. Introduction

Heat transfer is an important process which involve numerous applications in our daily life. It can range from conversion, utilization, and recovery of thermal energy in various industrial, commercial and domestic applications. It is an integral part in industries because heat must be efficiently added, removed of moved from one place to another. Many research works has been done in order to enhance heat transfer using a stationary twisted tape in these processes. Some common examples includes pharmaceuticals and agricultural products, steam generation and condensation in power and cogeneration plants, fluid heating in manufacturing and waste recovery units. Thus, there is a strong demand for heat augmentation techniques of forced heat transfer. Previously, the researches were limited to modified twisted tape, plain twisted tape and modified twisted tape geometry. The use of rotating twisted tape is a new concept. Due to lack of experimental data, the information on rotating twisted tape, in open literature, is limited. This paper presents a novel study on how a rotating twisted tape can enhance heat transfer without modifying the twisted tape by placing additional geometrical features.

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There are a number of research works done previously in order to investigate the heat transfer characteristics using twisted tapes. Eiamsa-ard et al. (2006) experimentally investigated on the heat transfer enhancement and friction factor characteristics in a double pipe heat exchanger fitted with a regular twisted tape insert. By comparing the result with plain tube, it was found that the heat transfer coefficient increased with twist ratio and spacing between two twisted tapes. Mengna et al. (2007) used a converging-diverging tube with evenly spaced twisted tape to investigate the pressure drop and compound heat transfer characteristics experimentally. By varying twist ratio and rotation angle various swirl patterns were generated. Promvonge and Eiamsa-ard (2007) used a circular tube fitted with conical-ring and a twisted tape swirl generator in order to investigate the thermal characteristics. It was found that the tube fitted with the conical-ring and twisted tape provides Nusselt number values of around 4 to 10% and enhancement efficiency of 4 to 8% higher than that with the conical ring alone. Chang et al. (2008) experimentally studied the turbulent heat transfer characteristics in a swinging tube with a serrated twisted tube insert undersea going conditions. This swirl tube swings about two orthogonal axes under single and compound rolling and pitching oscillations. Synergistic effects of compound rolling and pitching oscillations with either harmonic or non-harmonic rhythms increase heat transfer performances. Hata and Masuzakib (2010) investigated the twisted tape induced swirl flow heat transfer due to exponentially increasing heat inputs with various exponential periods and the twisted tape-induced pressure drop. The influence of Reynolds number based on swirl velocity for the twisted tape-induced swirl flow heat transfer was investigated and predictable correlation was derived. Changhong Chen et al. (2011) analyzed the Computational Fluid Dynamics (CFD) modeling for the optimization of regularly spaced short-length twisted tape in a circular tube. The parameters are given by the spacing between two twisted tapes, twist ratio and twist angle. It was found that the mean heat transfer and flow resistance increase with an increase in twist angle.

2. Methodology

Figure 1 shows the schematic diagram of the experimental setup that has been used in the research work. The experiment was done in two phases. The first phase consists of investigation of the heat transfer characteristics without using the insert. The second phase consists of investigation of heat transfer characteristics using a rotating insert at various RPM. A variac of 1 kVA specification was used to apply a constant voltage of 220 volts across the Nichrome wire wound over the outer surface of a copper pipe. A plain twisted tape of twist ratio of 5.25 (pitch=105 mm and width=20 mm) is inserted inside the copper pipe and supported by three bearings. The experiment starts with raising the temperature of the test section with the help of variac. After some time, the temperature reaches a steady state. The temperatures are displayed in a microcontroller based temperature measurement unit. Six LM35 sensors were placed at the outer surface of the pipe test section to determine the average surface temperatures. Two separate sensors were placed at the inlet and outlet housing for determining the water inlet and outlet temperature.

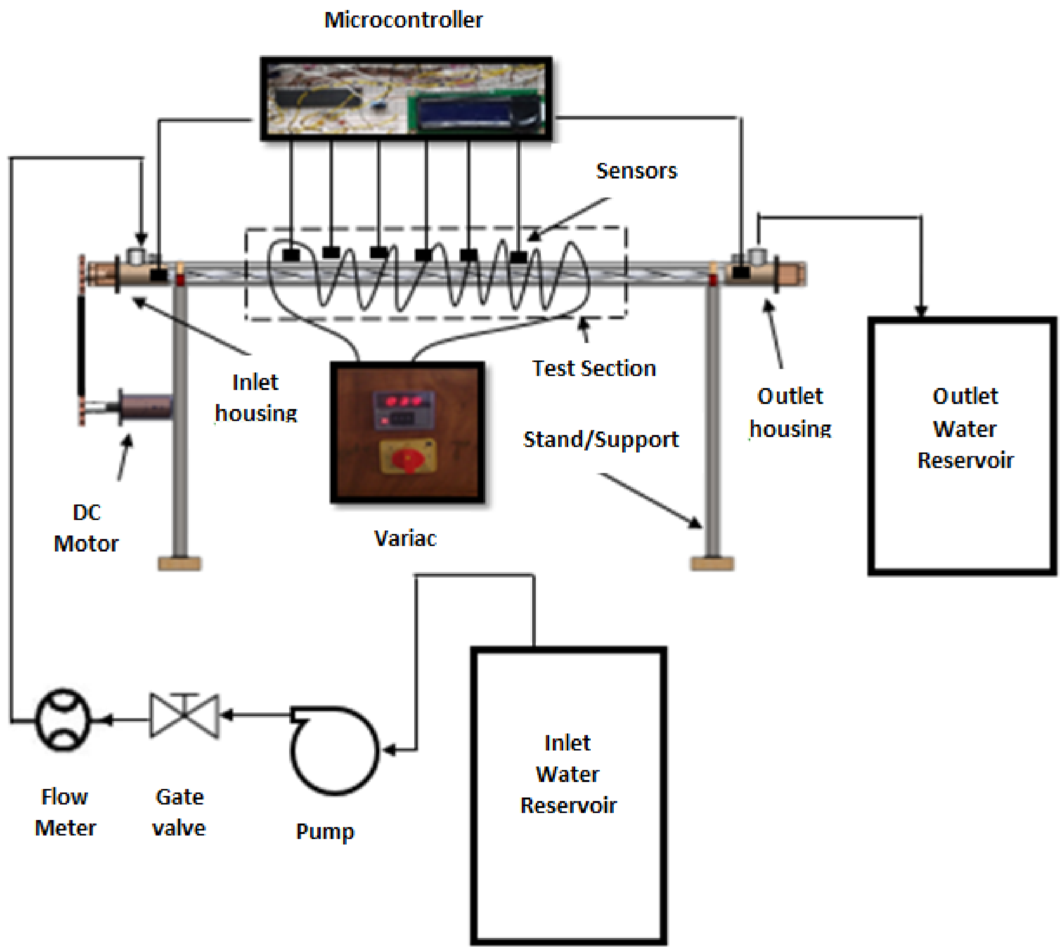

Figure 1: Schematic Diagram of Experimental Setup.

When the temperature does not change for 2-3 minutes, a 0.5 HP centrifugal pump is opened to circulate the water at room temperature to circulate through the pipe. The flow rate of the pump was set by using a gate valve. The flow rate was measured using a flow meter. For the first phase of the experiment in the smooth pipe, the desired flow rate was set and temperature was recorded when it reached a steady state value. Similarly, in the second phase the RPM of the rotating twisted tape was set by using a RPM controller. The RPM was measured using a tachometer. By applying the desired flow rate and RPM, the temperatures were recorded when it reached a steady state value.

Table 1: Material and Dimension of the Setup

Particulars	Specifications
Copper pipe	4 ft length, 39 mm inner diameter
Water pump	0.5 HP
Flow meter	18 LPM Max flow rate
Variac	1 kVA, 4 Amp
Operating range of LM35	-55^{o}C to 150 ^{o}C
Housing material	Brass

Table 2: Experimental conditions

Variable	Range
Water inlet temperature	25-35^{o}C
Flow Rate of Water	8-16 LPM
RPM of Twisted Tape	0-600 RPM
Mass flow Rate of Water	0.1296-0.2623 kg/s

3. Calculation Methodology

The heat added by the heater was calculated by the heat added to the water. Heat added to the water was calculated by,

$$Q = \dot{m} C_p \Delta T \tag{1}$$

where, $\dot{m}$ is mass flow rate of water, C_p is specific heat capacity of water and ΔT is difference between inlet and outlet temperature.

Heat transfer coefficient was calculated from,

$$h = \frac{q"}{(T_{wi} - T_b)} \tag{2}$$

where q” is the heat flux, T_{wi} is the average inner surface temperature and T_b is the bulk temperature.

Tube outer surface temperature was calculated from the average of six local tube outer surface temperatures,

$$T_{wo} = \sum_{i=1}^{6} \frac{T_{wo,i}}{6} \tag{3}$$

where T_{wo} is the average outer surface temperature and $T_{wo,i}$ is the local outer surface temperature.

Tube inner surface temperatures were calculated from one dimensional radial conduction equation,

$$T_{wi} = T_{wo} - Q.\frac{\ln\left({}^{d_o}/_{d_i}\right)}{2\pi K_w L} \tag{4}$$

where T_{wi} is the inner surface temperature, T_{wo} is the average outer surface temperature, Q is the heat added to water, d_o is the outer diameter of pipe, d_i is the inner diameter of pipe, K_w is the thermal conductivity of copper pipe and L is the length of test section.

Reynolds number was calculated from,

$$Re = \frac{4\dot{m}}{\pi d_i \mu} \tag{5}$$

where $\dot{m}$ is the mass flow rate of water, d_i is the inner diameter of pipe and μ is the dynamic viscosity of water at a particular bulk temperature.

Nusselt number was calculated from,

$$Nu = \frac{\mathrm{h} d_i}{k} \tag{6}$$

where h is the heat transfer coefficient, d_i is the inner diameter of pipe, and k is the thermal conductivity of the water at corresponding bulk temperature.

Heat transfer enhancement efficiency was calculated from,

$$\eta = \left|\frac{h_e}{h_s}\right| \tag{7}$$

where h_s is the heat transfer coefficient of smooth pipe configuration and h_e is the heat transfer coefficient of the pipe flow using rotating twisted tape insert.

4. Result and Discussion

The heat transfer characteristics of the experiment using a rotating twisted tape insert are illustrated from figure 2 to 5. The investigation of heat transfer characteristics includes the Nusselt number, Reynolds number, heat flux, bulk temperature, inner surface temperature and heat enhancement efficiency at various flow rate of water and RPM of rotating twisted tapes.

The effect of Reynolds number for different flow rates on Nusselt number is shown in figure 2. The result suggests that, Nusselt number for tube with tape insert is comparatively higher than Nusselt number in smooth tube. However, both values keeps on increasing as the flow rate increases. On the other hand, the value of Nusselt number keeps on increasing significantly as the RPM of the twisted tape is increased. With increase of both RPM and Reynolds number, higher values of Nusselt number can be obtained. For the experiment the highest value of Nusselt number was obtained at a mass flow rate of 0.2623 kg/sec and the rotation of twisted tape was at 600 RPM. However, the results hints that this Nusselt number could have been increased at higher flow rate and RPM.

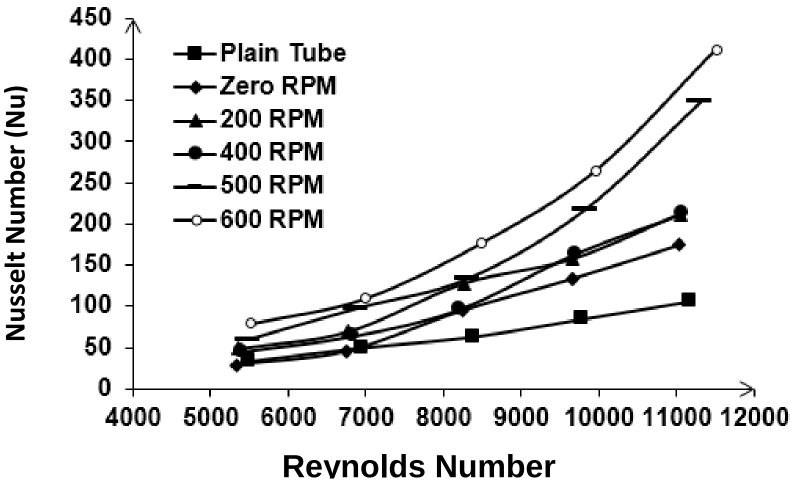

Figure 2: Variation of Nusselt Number with Reynolds Number for Different Flow Rate and Rotation of Twisted Tape.

The effect of Reynolds number for different flow rates on heat flux is shown in figure 3. The result suggests that heat flux for tube with tape insert is comparatively higher than heat flux in smooth tube. However both values keeps on increasing as the flow rate increases. Initially for rotation of twisted tape between 0-400 RPM, the heat flux remains comparatively lower than the heat flux at smooth pipe with Reynolds number in the range of 5000-8000. On the other hand, the value of heat flux keeps on increasing significantly as the RPM of the twisted tape is increased. With increase of both RPM and Reynolds number higher values of heat flux can be obtained. For this experiment, the highest value of heat flux was obtained at a mass flow rate of 0.2623 kg/sec and the rotation of twisted tape was at 600 RPM. However, the results suggests that this heat flux could have been increased at higher flow rate and RPM.

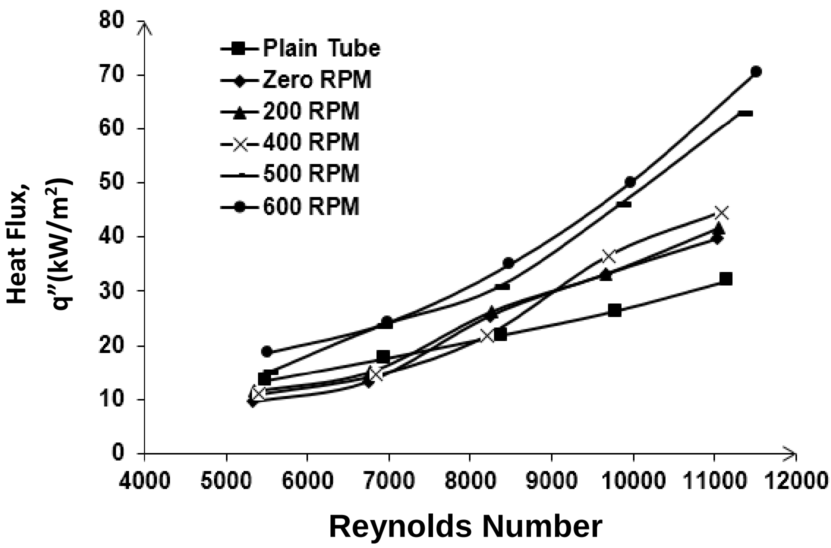

Figure 3: Variation of Heat Flux with Reynolds Number for Different Flow Rate and Rotation of Twisted Tape.

The effect of Reynolds number for different flow rates on tube inner surface temperature is shown in figure 4. The result suggests that tube inner surface temperature for tube with tape insert is comparatively lower than tube inner surface temperature in smooth tube. However, both values keeps on decreasing as the flow rate decreases. On the other hand, the value of tube inner surface temperature keeps on decreasing significantly as the RPM of the twisted tape is increased. With increase of both RPM and Reynolds number lower values of tube inner surface temperature can be obtained. However, the results hints that this tube inner surface temperature could have been decreased at higher flow rate and RPM.

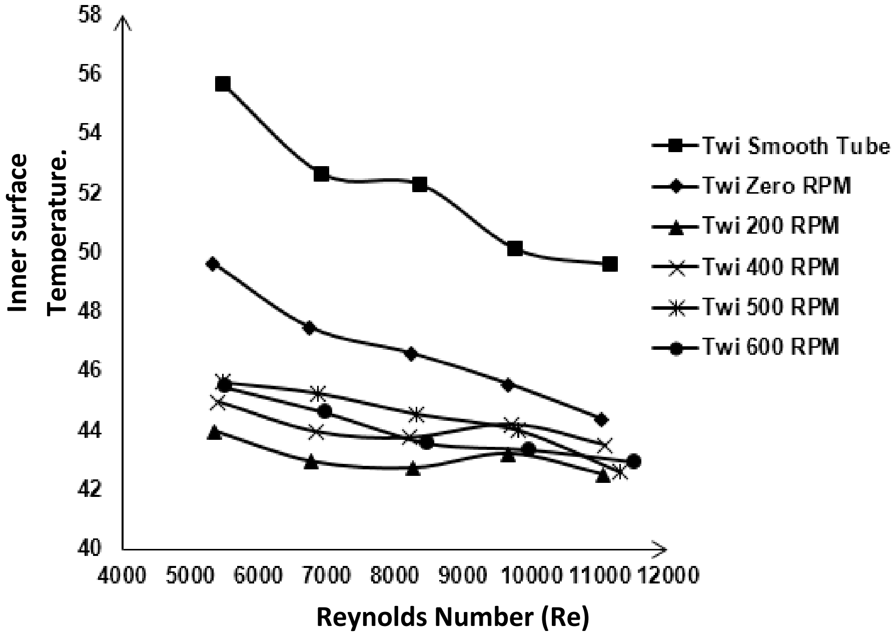

Figure 4: Variation of Inner Surface Temperature with Reynolds Number for Different Flow Rate and Rotation of Twisted Tape

The effect of Reynolds number for different flow rates on heat transfer enhancement efficiency is shown in figure 5. The result suggests that heat transfer enhancement efficiency for tube with tape insert can be significantly increased as the RPM of the twisted tape is increased. With increase of both RPM and Reynolds number higher values of heat transfer enhancement efficiency can be obtained. For this experiment the highest value of heat transfer enhancement efficiency was obtained at a mass flow rate of 0.2623 kg/sec and the rotation of twisted tape was at 600 RPM. The highest heat transfer enhancement efficiency was 3.87. For heat transfer without using the insert, the lowest heat transfer enhancement efficiency was obtained which was 0.87. However, the results hints that this heat transfer enhancement efficiency could have been increased at higher flow rate and RPM.

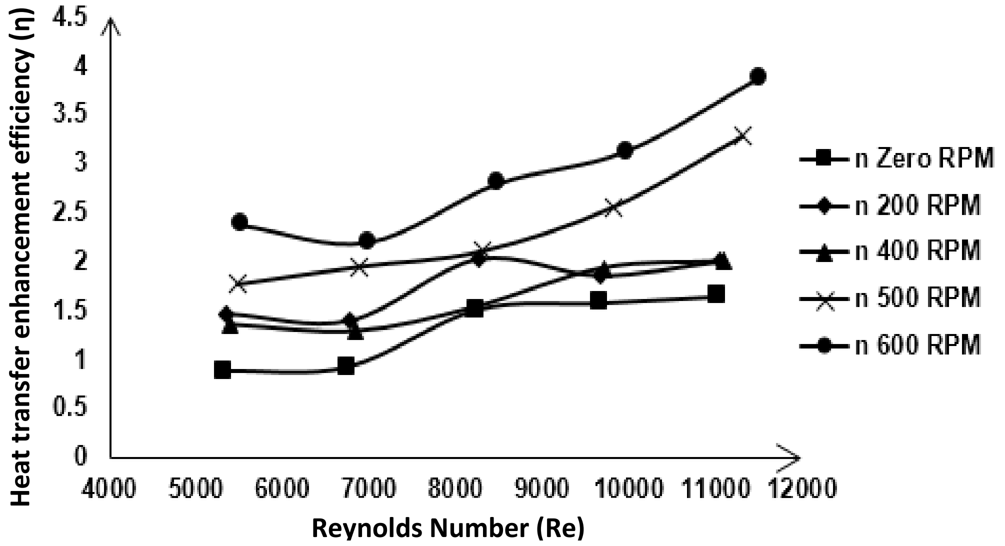

Figure 5: Variation of Heat Transfer Enhancement Efficiency with Reynolds Number for Different Flow Rate and Rotation of Twisted Tape.

5. Conclusions

This paper presents the comprehensive study on the heat transfer characteristics using rotating twisted tape insert. This work make use of the concept of heat enhancement to develop a design methodology. According to the study, heat transfer rate is greatly influenced by the flow rate of the fluid flowing in the system. Higher heat transfer rate can be obtained at high RPM of twisted tape and flow rate of flowing water. For heat enhancement using twisted tape, the methods used in the experiments were promising. Although, this method had helped us to understand the significance of RPM and flow rate that govern the heat transfer characteristics. There is still need of further research to conclude the systems behavior with inclusion of the friction factor parameter.

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