

# Experimental Investigation on Heat Transfer Enhancement in a Pipe Flow Using a Rotating Twisted Tape Insert

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**Abstract** Numerous works have been carried out by researchers into the physics of heat transfer in pipe flow. The current work aims at the enhancement of heat transfer rate in circular cross-sectioned pipe flow using rotating twisted tape insert. The novelty of this work lies within the employment of rotating twisted pipe insert for obtaining a greater heat transfer rate. An effort is given herewith to observe the effect of varying combination of rotational speed of the twisted tape insert, and volume flow rate of fluid on the overall heat transfer coefficient, heat transfer rate and heat transfer enhancement efficiency of the system. A physical model of the experimental setup was designed, built and instrumented for temperature measurements, which are used for the determination of the different performance characteristics. The volume flow rate of fluid was varied from 8 LPM to 16 LPM and the rotation of twisted tape was varied from 0 RPM to 600 RPM. The effects of relevant parameters experimental setup are investigated.

**Keywords:** heat transfer enhancement, experimental heat transfer study, forced convection heat transfer

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## 1. Introduction

Convective heat transfer has a growing demand in the industry with the development in chemical and process engineering. To increase effective heat transfer, forced convection can be implemented, which would improve the overall thermal performance of the heat exchanger. This requires an in-depth study on the heat transfer process.

Efforts have been given to investigate the effect of twisted tape insert inside the pipe for enhancing the heat transfer performance of the system.

Hejazi et al. [1] conducted experimental investigation of twisted tape insert's performance on condensation of HFC-134A refrigerant. The outcome of their study suggests an optimal twist ratio for obtaining heat transfer enhancement and minimum pressure drop across the system.

Sundar et al. [2] studied on the thermophysical properties of  $\text{Al}_2\text{O}_3$  Nanofluid in presence of twisted tape and found out significant increase of heat transfer coefficient when compared to water in similar configuration.

Eiamsa-ard et al. [3] compared heat transfer, friction factor and thermal performance amongst twisted tape inserts and constant and varying pitch ratio wire coils. An increase in thermal performance was registered by the

authors for wire coil with decreasing and increasing pitch ratio.

Klaczak [4] experimented on the heat transfer performance in laminar pipe flow with twisted tape inserts.

Ferroni et al. [5] studied on the pressure drop on isothermal pipe flow with twisted tape inserts and developed correlation of pressure drop in terms of Reynolds number, twist ratio and spacing.

Wang et al [6] developed an optimization routine based on computational fluid dynamics tools for turbulent heat transfer in pipe flow with twisted tape inserts.

Yadav [7] investigated on the effect of having twisted tape inserts inside partial region of pipe flow in heat transfer performance, and compared the results with plain tube heat exchangers.

Eiamsa-ard et al. [8] and Eiamsa-ard [10] studied on the thermal performance of pipe type heat exchanger with multiple twisted tape inserts.

Hataa et al [9] studied on the thermal and flow characteristics of a turbulent channel flow with twisted tape inserts.

This work focuses on the physics of heat transfer process pertaining to forced convection in pipe flow. The heat transfer process is enhanced using a rotating twisted tape. The underlying goal of this work was to investigate the effect of rotation on the thermal performance of the system. To achieve that, the rotational speed of the twisted

tape insert was varied, along with the flow rate, and the results are presented for varying Reynolds number.

## 2. Experimental Setup

### 2.1.1. Design of Experimental Setup

The strategy of the experimental procedure is focused on having a standard test setup to observe the effects of the combination of varying Reynolds number and the flow agitation on the convective heat transfer process in a pipe flow.

The experimental setup consists of a 1219 mm long circular Copper tube with 42 mm outer diameter and 1.5 mm wall thickness. A test section of 900 mm is fabricated with the rest of the tube used to facilitate the sensorics and the flow agitation system. The schematic diagram of the tube along with the test section is shown in Figure 1.

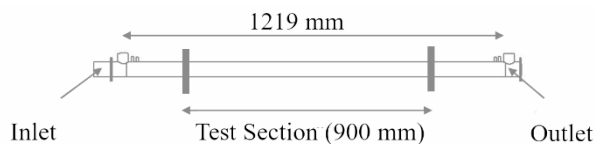


Figure 1. Schematic Diagram of Experimental Setup

To change the dynamics of the convective heat transfer process, the system was facilitated with a rotating twisted tape insert. The tape was constructed by twisting a 2 mm thick stainless steel flat bar along its longitudinal axis with a pitch  $P$  of 105 mm and a twist ratio ( $P/b$ ) of 5.25. Hence the flat bar had a width  $b$  of 20 mm. Figure 2 depicts the twisted tape insert used in this work.

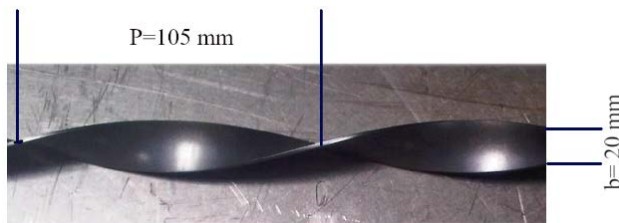


Figure 2. Twisted Tape Insert

Provisions have been made to support the rotating twisted tape system inside the copper tube. The tape is mounted with a gear assembly on one end and is kept free on the other end. The gear assembly was connected to the 24 V DC drive motor with the help of a chain drive system. A speed controller was used to control the rotational speed of the motor. The speed of the tape was controlled by adjusting the speed of the drive motor and was verified using digital tachometer. Figure 3 illustrates the components of the drive system of the twisted tape insert.

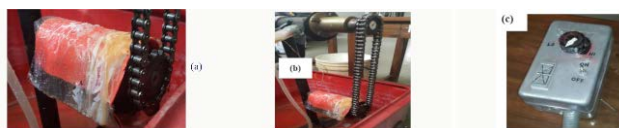


Figure 3. Drive System of Twisted Tape

Figure 4 depicts the construction drawing of the drive gear assembly attached to the twisted tape. The twisted

tape was connected to the driven gear with the help of a set of nuts and bolts. The system was designed to allow quick replacement of the twisted tape variants.

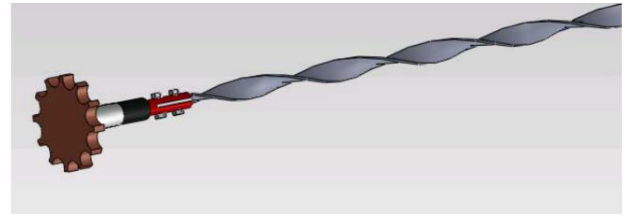


Figure 4. Drive System for Twisted Tape's Rotation

To support the drive system, the inlet housing was designed as an outer shell which was connected to the copper tube. Figure 5 depicts the design of the inlet housing section. Fluid was supplied into the tube through a vertical socket of 39 mm inner diameter. The copper tube section was inserted into the inlet section. Vertical holes were provided to mount the pressure and temperature sensors.

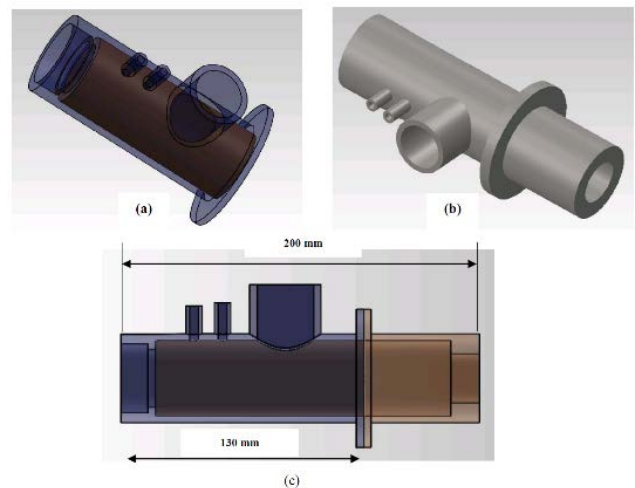


Figure 5. Inlet Housing.

Figure 6 depicts the construction drawing of the outlet housing. The copper tube was inserted to the outlet housing which had similar provisions of attaching pressure and temperature sensors and had an outlet port of 39 mm inner diameter.

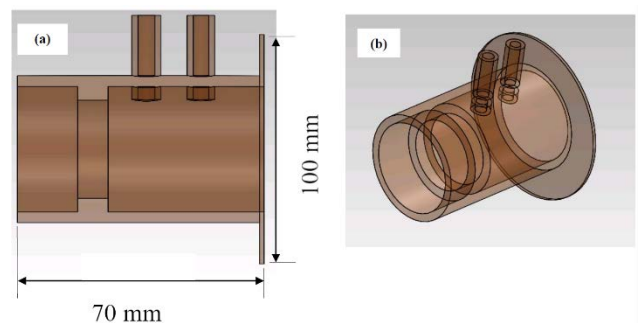


Figure 6. Outlet Housing

The schematics of the complete experimental setup is depicted in Figure 7. The flow circuit consists of a reservoir, a 0.5 HP centrifugal pump, a gate valve to control the flow rate, a rotameter to measure the flow rate, and a sink. The test section was wound with Aluminosilicate electrical

insulation tape, Nichrome wire with internal resistance of 18  $\Omega$ m for facilitating electrical heating, fiber glass cloth, foil tape, and 40 mm thick asbestos tape for thermal insulation. A 1 KVA variac was used to control the electrical heating system. Six LM35A integrated circuit temperature sensors were installed on the surface of the copper tube to measure the surface temperature within the test section. Two separate LM35A sensors were used at the in-and outlet to measure the temperature of the fluid at those sections. The outputs of the temperature sensors were fed to a PIC 18F452 microcontroller for data logging. Differential pressure measurement of the fluid between the in- and outlet sections were carried out by attaching the pressure taps to a u-tube manometer.

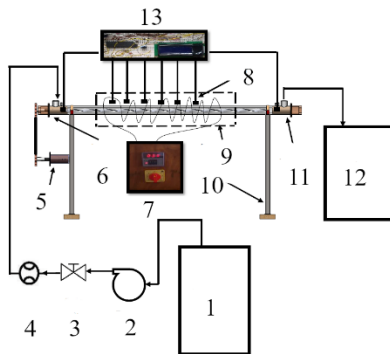


Figure 7. Schematic Diagram of Experimental Setup

Figure 8 depicts the completed experimental setup with supporting structure.



Figure 8. Experimental Setup

### 2.1.2. Data Acquisition

The following sensors/data acquisition modules were used to measure the system variables:

| Sl | Data Acquisition                     |                            |                                                                    |
|----|--------------------------------------|----------------------------|--------------------------------------------------------------------|
|    | Variable                             | Sensor/Controller          | Mode/Specification                                                 |
| 1  | Rotational speed                     | Tachometer                 | Infrared type, digital display                                     |
| 2  | Flow rate                            | Rotameter                  | Manual, max range 5 GPM                                            |
| 3  | Temperature                          | LM35A                      | Integrated circuit, range (-10°C to 25°C), $\pm 0.2^\circ\text{C}$ |
| 4  | Data logging of temperature readings | PIC 18F452 Microcontroller | DIP 40-pin Microcontroller                                         |
| 5  | Heating rate                         | 1 KVA variac               | -                                                                  |

## 3. Results

The working fluid for the experiments was taken as line water of inlet temperature 25-35°C. All readings were taken after steady states had been obtained from the temperature sensors. The baseline experiments (plain tube) were carried out with no twisted tape insert. Flow rate of the water was varied within the range of (8, 10, 12, 14 and 16 l/min). With the twisted tape inserted in the copper tube, experiments were conducted at (200, 400, 500 and 600 rpm) of the tape. The electrical heating of the copper tube was kept at a constant by operating the variac at (220V and 4A).

### 3.1.1. Flow Characteristics Numbers

The working fluid for the experiments was taken as line- water of inlet temperature  $T_{(in)}$ , outlet temperature  $T_{(out)}$ , density  $\rho$ , dynamic viscosity  $\mu$ , volume flow rate  $v$ , and mass flow rate  $m$ .

The test section of the pipe had an inner diameter  $d_i$  and length  $L$ .

Flow Reynolds number had been calculated as

$$Re = \rho v L / \mu = 4m / \pi d_i \mu$$

The system Nusselt number had been calculated as

$$Nu = h d_i / \kappa$$

Hence, the convective heat transfer coefficient:

$$h = q / (T_{wi} - T_b)$$

and the bulk temperature of the fluid within the system:

$$T_b = \frac{T_{in} + T_{out}}{2}$$

The tube inner surface temperature had been calculated from the one dimensional radial heat conduction equation of hollow tube as:

$$T_{wi} = T_{wo} - Q(\ln(d_o / d_i) / 2\pi k_w L)$$

Hence tube outer surface temperature had been calculated as the average of the LM35A readings at six locations within the test section as:

$$T_{wo} = \sum_{i=1}^6 \frac{T_{(wo,i)}}{6}$$

### 3.1.2. Experimental Analysis

The effect of Reynolds number for different flow rates on Nusselt number is shown in Figure 9. The result suggests that Nusselt number for tube with tape insert is comparatively higher than Nusselt number in smooth tube. However, both values keep 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.

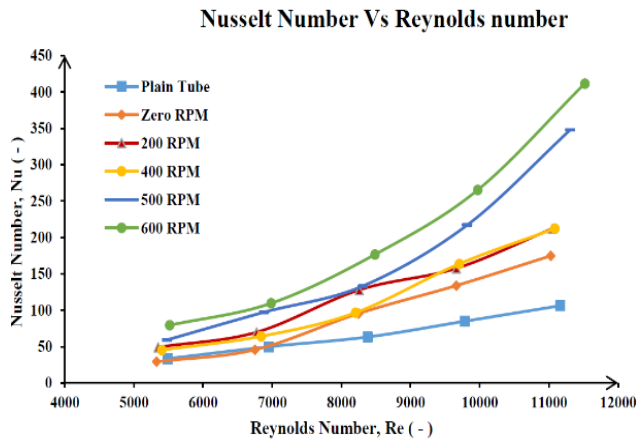


Figure 9. Nusselt Number vs Reynolds Number

The effect of Reynolds number for different flow rates on heat flux is shown in figure 10. The result suggests that heat flux for tube with tape insert is comparatively higher than heat flux in smooth tube. However, both values keep 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 through 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 the 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.

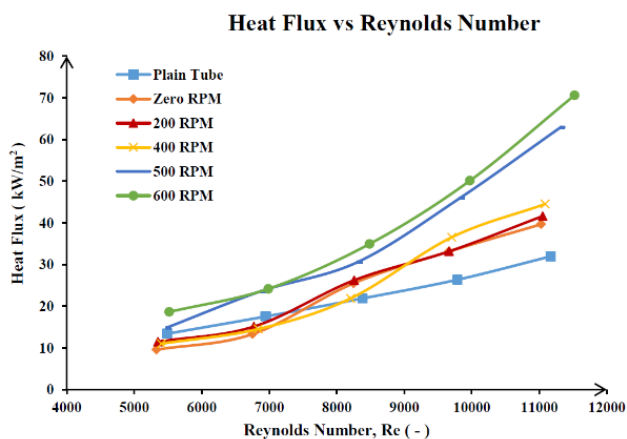


Figure 10. Heat Flux vs Reynolds Number

The effect of Reynolds number for different flow rates on bulk temperature is shown in Figure 11. The result suggests that bulk temperature for tube with tape insert is comparatively higher than bulk temperature in smooth tube. However, both values keep on increasing as the flow rate increases. Initially, for rotation of twisted tape between 0-400 RPM, the bulk temperature remains comparatively lower than the bulk temperature at smooth pipe with Reynolds number in the range of 5000-8000. On the other hand, the value of bulk temperature keeps on increasing 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. For this experiment, the lowest value of bulk temperature was obtained at a mass flow rate of 0.2623 kg/sec and the rotation of twisted tape was at 600 RPM.

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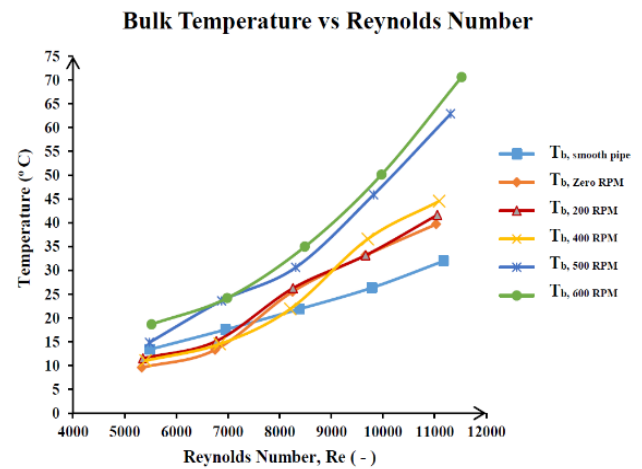


Figure 11. Bulk Temperature vs Reynolds Number.

The effect of Reynolds number for different flow rates on tube inner surface temperature is shown in Figure 12. 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 keep on decreasing as the flow rate is decreasing. 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. For this experiment, the lowest value of bulk temperature was obtained at a mass flow rate of 0.2623 kg/sec and the rotation of twisted tape was at 600 RPM.

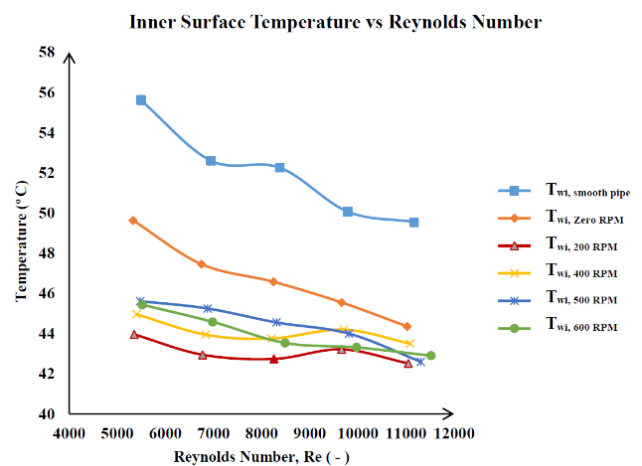


Figure 12. Inner Surface Temperature vs Reynolds Number

The effect of Reynolds number on the heat transfer enhancement efficiency is shown in Figure 13. The results for different rotational speed of the twisted tape insert are included in the depiction. Heat transfer enhancement efficiency is increased for higher Reynolds number. Additionally, the rotational speed of the twisted tape insert has a positive impact on the heat transfer enhancement.



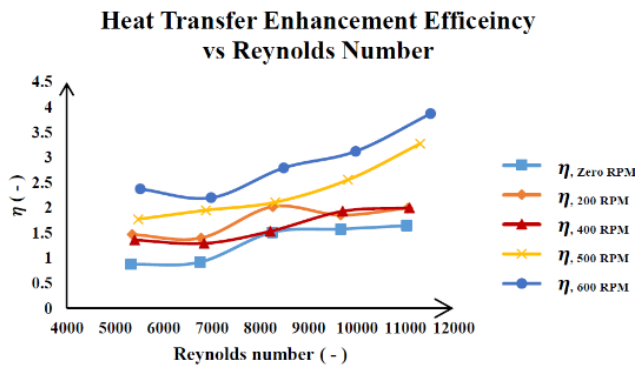


Figure 13. Heat Transfer Enhancement Efficiency vs Reynolds Number

### 3.1.3. Discussion

This study presents the new experimental data on heat transfer characteristics using rotating twisted tape insert. This work makes use of the concept of heat enhancement to develop a design methodology. The application of this approach result in a simple, quick and easy implementation of the methodology. 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 system's behavior with response to the friction factor.

## 4. Conclusions

This paper documents the experimental setup, data acquisition system and the experimental investigation on the effect of having a rotating twisted-tape insert inside a pipe. Bulk characteristic flow numbers are calculated using the flow variables measured during the experiments. The following conclusions can be drawn from the experimental results presented in this paper. The inclusion of a twisted tape insert enhances the effectiveness of the tubular heat transfer system. It is seen that the effect of increased flow rate has a positive effect on the heat transfer rate. The rotational speed of the twisted tape insert

further enhances the heat transfer rate. The results are in line with the theoretical understanding of the system.

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