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Experimental Heat Transfer Investigations of a Double Pipe U-Tube Heat Exchanger Equipped with Twisted Tape and Cut Twisted Tape Internals

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Abstract. For several decades, the use of heat exchangers for both heating and cooling applications has been established in industries ranging from process to space heating. Out of the various types of heat exchangers, U-tube heat exchangers are preferred owing to their abilities to handle larger flowrates and their simplicity in construction. U-tube exchangers are often equipped with innards of various forms which facilitate higher heat transfer rates and thermal efficiencies. Although higher heat transfer rates have been established with the addition of internals, there is a lack of coherence on the underlying complex physical phenomena such as heat transfer boundary layers and turbulence characteristics. In the current study, the effect of twisted and cut-twisted tape inserts on heat transfer enhancement and pressure drop in a counter flow double pipe U-tube heat exchanger has been investigated using experimental approach. This has been compared with bare tubes in the absence of internals. Physical parameters such as heat transfer rate, pressure drop, Nusselt number are determined for a range of mass flow rates.

Keywords: Heat exchangers, Heat transfer, Twisted tape internals, Cut-twisted tape internals, Counter-Flow

INTRODUCTION

With the increasing demand for natural resources, an "energy crisis" in the near future is imminent. But it is dependent on our willingness to shift to clean and novel energy sources. Energy consumption as an area of critical interest has gained a lot of traction over the last few decades. Innovations in heating or cooling in industrial processes have resulted in improved energy efficiencies, and extended lifespan of process equipment, while making better economic sense at large. Heat exchangers have found their prominence in many industrial applications such as chemical and petrochemical processing, food manufacturing, power generation, heat recovery systems, and nuclear plants, to name just a few[1–4]. Heat exchangers are applied to facilitate heat transfer between hot fluid and cold fluid streams. The walls of the heat exchanger tubes facilitate the conduction and convection mechanism to transfer thermal energy from hot fluid to cold fluid. Over a long span, considerable progress has been made in the improvement of heat transfer times and thermal efficiencies in a heat exchanger. The methods that are employed to increase convective heat transfer coefficients are classified as active and passive techniques[5–7]. The former technique requires the use of an external energy source to enhance heat transfer efficiency. The latter, however, is dependent on the modification of geometry by the addition of various types of innards which induces turbulence within the system – thereby increasing the efficacy of heat transfer. Turbulence is further propagated due to the presence of swirling, vortical, and secondary flows which are a consequence of geometry modification [8]. To date, a variety of tube inserts have been employed in a number of studies, some of which include twisted tapes, coiled wires, helical screws and conical screws.

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In one of the early works carried out by Date (1947) [9], a tube occluded with twisted tape inserts was used to analyze flows in various regimes. The presence of twisted tape inserts reportedly led to an increase in heat transfer rate with an increase in pressure drop. It was suggested that the transport equations derived for the twisted tape flows were found to inadequately predict the flow behavior. Due to this, reduced values of friction factor and Nusselt number were reported. In another study by Manglik and Bergles (1993) [10], friction factor and Nusselt number correlations for laminar flow in a tube fitted with twisted tape inserts are provided. Similar to the observations of Date (1947) [9], heat transfer was enhanced due to the effect of secondary flow circulations, longer flow paths, and tube sectioning. A correlation between heat transfer and swirl flows was developed for tape-induced swirling flows.

In their work, Chang et al. (2007)[11], have experimentally investigated the effect of broken twist tape inserts with various twist ratios on the heat transfer characteristics of a heat exchanger. Nusselt number increased by 1.28–2.4 times and 6.3–9.5 times for the broken twist tape inserts as compared to the continuous twist tape and bare tube without inserts, respectively. A higher swirling motion was reportedly induced in the presence of broken twist tape as compared to the continuous twist tape inserts. Similarly, the Fanning friction factor ratios were higher for the broken twist tape as compared to the continuous twist tape inserts. Rahimi et al. (2009) [12]have investigated the effects of classic and modified twisted tape inserts on heat transfer characteristics using experimental analysis and Computational Fluid Dynamics (CFD) simulations. It was reported that for a wide range of Reynolds number, higher Nusselt number and thermal-hydraulic performance was noticed with the modified inserts - these parameters increased by 31% and 22% respectively as compared to the classic internals. Numerical simulations revealed an increase in the turbulent intensities close to the wall in the presence of modified internals as compared to the classic type. In another numerical study, Tusar et al. (2019) [13] have investigated the effect of the insert's twist ratio on heat transfer and fluid hydrodynamics. Twist tapes with two twist ratios of 3.46 and 7.6 were analyzed. As expected, the Nusselt number and friction factor augmented with increasing Reynolds number. As compared to the bare tube, the addition of inserts with twist ratio of 3.46 and 7.6 increased the Nusselt number by 20–62% and 10–30%, respectively. Similarly, as compared to the bare tube, friction factor values enhanced in the range of 185–245% and 128–183% with the addition of inserts of twist ratios, 3.46 and 7.6, respectively. Thermal performance factor for twist ratios 3.46 and 7.6 was 0.9–1.2 and 0.95–1.02, respectively.

In the current work, experimental analysis is carried out to understand the effect of the addition of inserts in a double pipe heat exchanger. The influence of classical twisted tape and modified twisted tape inserts on heat transfer characteristics are studied. For the twisted tape and cut twisted tape, an h/d ratio of 3 is used and a depth of 1mm cut is used. The data obtained is compared with the bare tube in the absence of inserts. Physical parameters such as heat transfer rate, heat transfer coefficient, and pressure drop determined for a range of Reynolds numbers with water as working fluid.

Experimental Setup

The experimental setup consists of a test section two reservoirs (hot and cold tanks), centrifugal pumps, flow regulating valves, and a manometer as shown in Figure 1.The setup consists of two U-shaped pipes inserted in a hollow shell to represent a heat exchanger; the inner tubes are made up of copper to facilitate higher heat transfer rates. These have an inner diameter of 17 mm. The inner tube length is 1.5 m and the outer shell diameter is 60 mm. The material of construction for the shell is mild steel. The outer surface of the shell side tube is bound by a layer of asbestos insulation to curtail any heat losses from the experimental setup to the surrounding atmosphere. The inner tube is concentrical to the shell side tube and is completely encompassed within it. The hot and cold liquid is let into the shell side and the tube side, respectively, via a pump which is regulated using flow regulating valves. The volumetric flow rate of hot fluid (333 K) flowing through the shell is maintained unchanged (6 $Lmin^{-1}$). The range of mass flow rates of the cold fluid (295 K) is varied from 3–15 $Lmin^{-1}$. Two configurations of inserts have been used in the current study – classical (twisted) tape and modified (cut twisted) tape. These have been outlined in Figure 2.

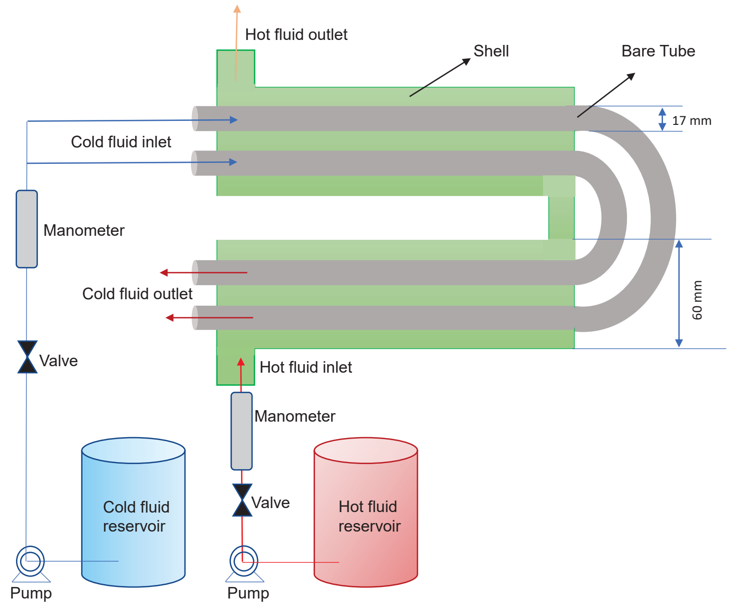

FIGURE 1. Experimental setup of the double pipe heat exchanger

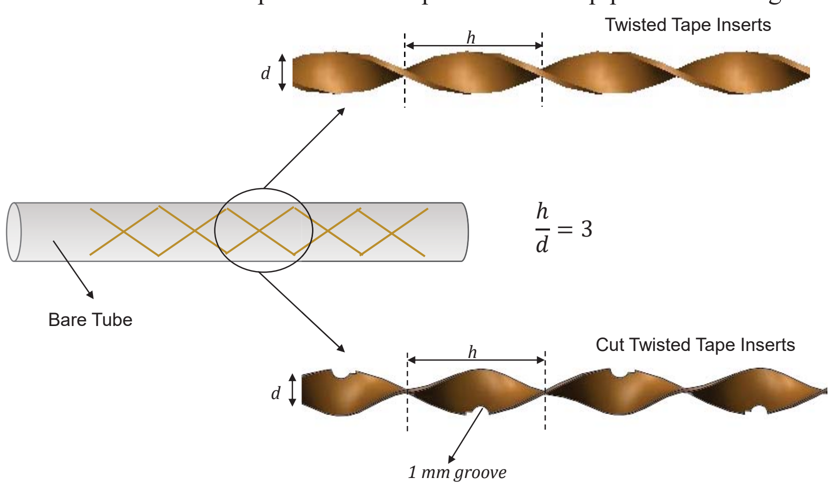

FIGURE 2. Representation of inserts used within the bare tube – twisted tape and cut twisted tape

Performance Parameters

The performance of the heat exchanger is quantified based on the rate of heat transfer occurring from the hot fluid side to the cold fluid side. Practically, in a heat exchanger, the heat from the hot fluid is transported to the outer wall of inner tubes via convection. Then heat is transferred to the inner walls via convection followed by its convection from the inner wall of the inner tube to the colder fluid. Therefore, to understand the complex conjugate heat transfer mechanism, one can introduce the Nusselt number which is described as the ratio between the convective and conductive heat transfer,

$$Nu = \frac{h_{avg} \cdot d_i}{k} \tag{1}$$

and the average heat transfer coefficient h_{avg} is calculated from the following relation

$$h_{avg} = \frac{Q_{avg}}{A_i \Delta T_{LMTD}} \tag{2}$$

where, $Q_{avg} = \frac{Q_c+Q_h}{2}$ and the Q for the cold side and the hot side is calculated by the classical heat transfer equation. Here, d_i is the inner tube diameter and k is the thermal conduction of the inner tube material. The Reynolds number that describes the ratio of inertial force to the viscous force is given as

$$Re = \frac{U \cdot d_i}{\vartheta}, \quad (3)$$

where U is the cold fluid velocity, ϑ is the kinematic viscosity of the cold fluid.

When a flow is obstructed by an insert that is placed in the flow direction, the pressure across the length of the tube tends to decrease. This adverse phenomenon is predominantly observed in heat exchangers. The pressure drop can be quantified using the friction factor f, given by

$$f = \frac{\Delta P}{(L/d_i)\cdot(\rho U^2/2)} \quad (4)$$

Here, ΔP denotes the pressure drop along the length of the heat exchanger, $L$is the inner tube length, d_i is the inner diameter of the bare tube, U and ρ are the velocity and density of water.

RESULTS AND DISCUSSION

The experimental results areconsistent withthe theoretical trends reported so far in the literature. Figure 3 (a) illustrates the variation of Nusselt number at different Reynolds numbers.It was evident that the magnitude of the Nusselt number greatly increased by adding the twisted tape inserts as compared to that of the bare tube.

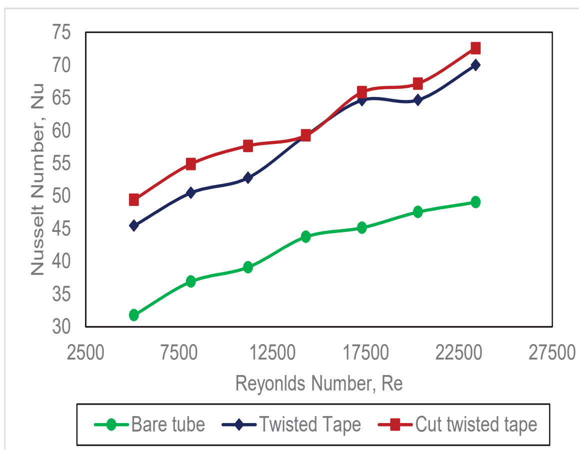

FIGURE 3. Comparison of Nusselt number at various Reynolds number for bare tube, twisted tape and cut twisted tape inserts

Theoretically, the deposition of a continuous thermal boundary layer results in a lower heat transfer rate [14], [15], which is in accordance to our observations when a bare tube was employed (see Fig 4). The higher heat transfer rate in the case of twisted tape and cut twisted tape could be attributed to the alteration of the thermal boundary layer which is in turndue to the swirling motion of the fluid. Similar observations were made in several literature studies [16]–[19]. From Figure 4, the rate of heat transfer with inserts has substantially augmented by 30.42% as compared to that of the bare tube. When the bare tube was occluded with cut twisted tape inserts, a better heat transfer rate was noticed, i.e. 6% higher than the classical twisted tape inserts.

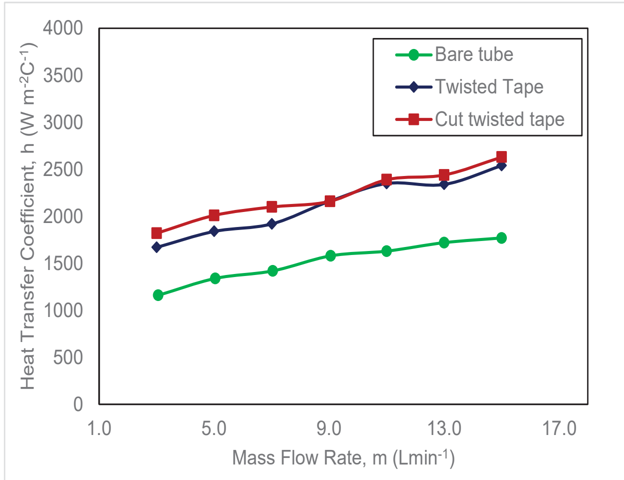

FIGURE 4. Comparison of heat transfer coefficient at various Reynolds number for bare tube, twisted tape and cut twisted tape inserts

In order to improve its performance, the pressure drop over the heat exchanger must be taken into account.From Figure 5, it is clearly evident that the coefficient of friction factorincreased with the addition of twisted and cut twisted tape inserts. Even though the pressure dropsbetween the twisted and cut twisted tape inserts were close, the drop in pressure from the bare tube to the twisted tape wassignificantly higher. Although the influence of inserts is quantitatively observed in the experiment, the complex physics involved in it is imperceptible. An insight into this can be gathered using advanced computational tools such as CFD analysis.

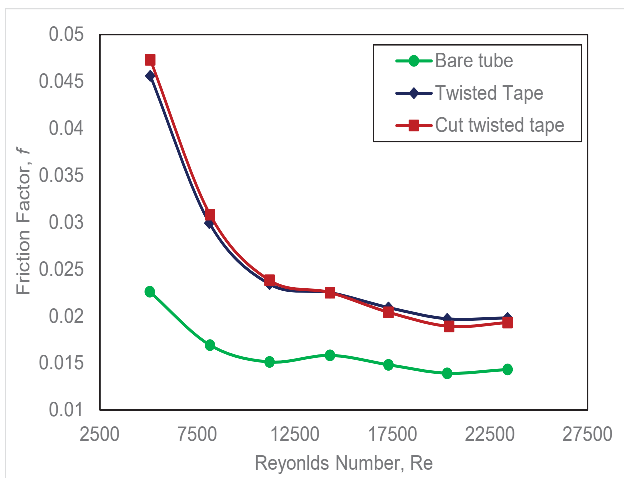

FIGURE 5. Comparison of friction factor at various Reynolds number for bare tube, twisted tape and cut twisted tape inserts

CONCLUSION

In the current study, the effect of the addition of inserts on the heat transfer characteristics is investigated. A comparison between the bare tube, twisted tape inserts, and cut twisted tape inserts, is made.An increase in the Nusselt number with increasing Reynolds number is noticed for all the cases. Heat transfer rate is significantly increased with twist tape and cut twist tape insertsas compared to plain tube.The average increase in the heat transfer coefficient is found to be 29.25% and 33.12% for twisted tape and cut twisted tape, respectivelyin reference to that of the bare tube. A significant increase in the friction factor values is noticed on the inclusion of inserts. This impliesan increase in pressure drop across the heat exchanger. Although superior thermal performance is noticed with the addition of inserts, an undesirable pressure drop is inevitable.

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