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Heat Transfer Enhancement in A Double Pipe Heat Exchanger with Rectangular Fins and A Twisted Tape Turbulator

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Abstract

This study investigates the heat transfer coefficients and pressure drop characteristics of a double-pipe heat exchanger (DPHX) equipped with rectangular longitudinal fins and a twisted tape insert as turbulator. Water flows through the inner pipe, while air circulates in the annular region. We varied important parameters like mass flow rate of water, length of heat exchanger, number and height of fin and number of twists in turbulator to do a numerical study in MATLAB. It was found that increasing fin height and number exponentially improved the heat transfer coefficient. Additionally, more twists and a higher mass flow rate further boosted heat transfer rates. A slight increase in pressure drop was offset by improved efficiency through proper design. Results showed that fins and twisted tape brought about a 10% increase in heat transfer coefficient and achieved a heat duty of 645 W—nearly 4 times that of the bare DPHX (161 W). These heat exchangers have huge applications in power generation and HVAC systems.

Keywords: Double pipe heat exchanger, rectangular longitudinal fin, twisted tape, heat transfer coefficient, pressure drop.

1. Introduction

Improving the thermal efficiency of heat exchanger is critical for optimizing energy consumption in industrial processes. Double-pipe heat exchangers (DPHX) are widely used around the world for their simplicity and effectiveness in facilitating heat transfer between fluids. However, further enhancements in energy efficiency require increasing the heat transfer coefficient. One of the most effective is using of extended surfaces like fins, which increase the surface area available for heat exchange. Additionally, in forced convection, especially at higher Reynolds numbers, creating turbulence or swirl in the flow can further enhance heat transfer rates. Hence, combining fins and turbulators into DPHX may prove to be a promising approach, offering significant improvements in heat transfer while maintaining a compact design. In this study, we investigated the combined effect of rectangular longitudinal fins and a twisted tape turbulator on heat transfer and pressure drop performance and compared the results to those of a bare double-pipe heat exchanger.

Heat transfer enhancement has proven to depend on the fin geometry and the operating conditions. Over the years, many studies have investigated the effect of fin geometry on heat transfer in DPHX. Masliyah and Nandakumar [1] investigated the heat transfer rate for forced convection flow in a triangular-finned circular tube with uniform heat flux. For a given fin geometry, the Nusselt number based on the inside tube diameter was higher than that for a smooth tube. Nagarani et al. [2] used circular and elliptical annular fins as a heat enhancement device in a DPHX and observed higher fin efficiency for elliptical fins. Zhang et al. [3] reported an 87–115% improvement in heat transfer in DPHX with helical fins. Syed et al. [4] analyzed the heat transfer rate of finned double pipe heat exchanger using longitudinal fins of different tip thicknesses. He concluded that an increase of 170% occurred in the heat transfer coefficient by using this type of fins. Despite the widespread investigation of different fin geometries, the most basic design that is rectangular fin remains underexplored, particularly in optimizing their design to balance out pressure drop with heat transfer performance. Among the limited studies, Braga and Saboya [5] conducted notable work, providing valuable correlations for heat transfer and pressure drop

calculations. However, their study focused on specific flow conditions, leaving room for further exploration in more complex or turbulent regimes. Kumar [6] conducted numerical analysis for 3 different types of fin profiles – rectangular, triangular, and parabolic. He showed that rectangular fins provided the highest heat transfer coefficient but caused a greater pressure drop.

Twisted tape turbulators have long been used to enhance heat transfer in DPHX. These twisted metal bodies introduce swirl flow, increase turbulence and improve heat transfer along the pipe walls. Liao and Xin [7] studied the heat transfer and friction characteristics of continuous and segmented twisted tape inserts. Sarma et al. [8] proposed generalized correlations for predicting friction factors and convective heat transfer coefficients in tubes with twisted tapes, showing good agreement between predictions and experimental data. Sheikholeslami et al. [9] used numerical simulations to demonstrate that helically twisted tapes enhance heat transfer by reducing the thermal boundary layer through stronger secondary flow. According to Kumar et al. [10] twisted tapes with modified geometry can improve heat transfer at a reasonable pressure drop in both laminar and turbulent flows. Nakhchi and Esfahani [11] evaluated the double and single rectangular-cut twisted tape inserts and reported that increasing the cut depth raises the heat transfer rate due to better mixing.

Though numerous studies have independently investigated the effects of twisted tape turbulator inside the pipe and rectangular fins in the annular region on heat transfer performance, no studies till now have been conducted by incorporating both of these features. In this study, a numerical investigation was conducted to obtain friction factor, heat transfer coefficient and pressure drop in a DPHX with twisted turbulator and rectangular fins. Various parameters like mass flow rate, heat exchanger length, fin number and height, and number of twists were varied to observe the effect on heat transfer and pressure drop characteristics. Additionally, a performance comparison was made with a bare DPHX. This approach maximizes thermal efficiency and provides better performance than a basic DPHX.

2 Methodology

2.1 Physical Modeling

A physical model of the heat exchanger was first designed and constructed with required dimensions and specified materials. Figure 1 represents the final physical model of the heat exchanger. A twisted tape turbulator and rectangular longitudinal fin were incorporated to the basic DPHX to enhance heat transfer and maintain a moderate pressure drop. The inner pipe, made of copper (Cu), had an inner and outer diameter of 1.25 inches and 1.289 inches, respectively. Similarly, the outer pipe, made of mild steel (MS), had an inner and outer diameter of 2.25 inches and 2.368 inches respectively. A twisted tape turbulator of MS was placed inside the inner pipe, which had a length of 24 inches featuring 9 twists along its length, and a pitch of 2.667 inches. The turbulator had a rectangular cross section with 1 inch width and thickness of 0.12 inch. Eight rectangular longitudinal fins of MS were attached to outer surface of inner pipe across the 2 feet heat exchanger, with fin length of 0.315 inches and thickness of 0.05 inches was used. Copper was selected for its high thermal conductivity and mild steel was chosen for low cost and superior structural strength. The fabrication process involved welding of pipes, fins and turbulator, followed by pressure testing of the physical heat exchanger.

2.2 Numerical Modeling

Based on the dimension of physical modeling, a numerical model was constructed using MATLAB software (See supplementary material for reference). The assumptions for the numerical study included a small fouling factor, rust formation, material non-homogeneity and laminar flow. The primary objective was to improve the heat transfer coefficient while maintaining acceptable pressure drops. The heat transfer coefficient (U) and pressure drop (ΔP) characteristics of annulus and pipe were evaluated. The crossflow DPHX in the parametric study was designed with cold water flowing at 0.25 kg/s, entering at 55°C and air entering on the opposite end at with a flow rate of 0.1 kg/s. The working fluids on the inner tube and annulus area were hot water and air, respectively to achieve greater heat transfer between the two mediums. Th effect of varying mass flow rate, tube length, fin number and height, and number of twists in the turbulator were observed on the pressure drop characteristics and heat transfer coefficient. Using the numerical model, a comparison between basic DPHX and the DPHX with fin and turbulator was performed. For the modified version including fins and a turbulator, the empirical correlations from two separate papers were used to calculate friction factor and heat transfer coefficient. For the twisted turbulator in the inner pipe, correlations proposed by Naphon [12] were utilized, while for the fin in the annulus section, correlations by Braga and Saboya [5] were applied.

For the inner pipe, the Nusselt number and heat transfer coefficient were calculated using the following correlation:

$$Nu = \frac{hD}{k} = 0.648\, Re^{0.36} \left[1 + \frac{D}{H}\right]^{2.475} \mathrm{Pr}^{\frac{1}{3}} \quad (1)$$

Where Re is the Reynolds number, Pr is the Prandtl number, H is pitch and H/D is the twist ratio. Similarly, the friction factor was calculated as:

$$f = 3.517 Re^{-0.414} \left[1 + \frac{D}{H}\right]^{1.045} \quad (2)$$

Both equations are applicable where $7000 \leq Re \leq 23000$ & $3.1 \leq \frac{H}{D} \leq 5.5$

For the annular region, empirical correlations used are as follows:

$$Nu = \frac{hD}{k} = 0.0061 Re^{0.868} Pr^{-0.4} \quad (3)$$

$$f = 2.8467 Re^{-0.2863} \quad (4)$$

Both equations are applicable where $10^4 < Re < 5 \times 10^4$



Fig. 1. Fabricated design: final heat exchanger, cross sectional view with fins & twisted tape

2.3 Validation

The numerical model developed in MATLAB was validated against the existing work of Braga and Saboya [5], focusing on the heat exchanger design by incorporating only continuous rectangular longitudinal fins in the annulus region. The working mediums and dimensions used in the study by Braga and Saboya [5] were similar to those in our numerical model. Consequently, despite using different materials, the results obtained using the numerical model showed closer agreement, with a deviation less than 5%. The observed discrepancies can be attributed to the assumption made in our model which was absent in the experiment by Braga and Saboya.

3. Results and Discussion

This section presents the findings from the numerical study conducted using MATLAB. The performance of our modified heat exchanger, equipped with rectangular fins and a twisted tape turbulator, is compared to a bare tube heat exchanger. The effect of varying key design parameters on the performance of heat exchanger has been examined and represented in the following graphs.

3.1 Performance comparison between modified and basic heat exchanger

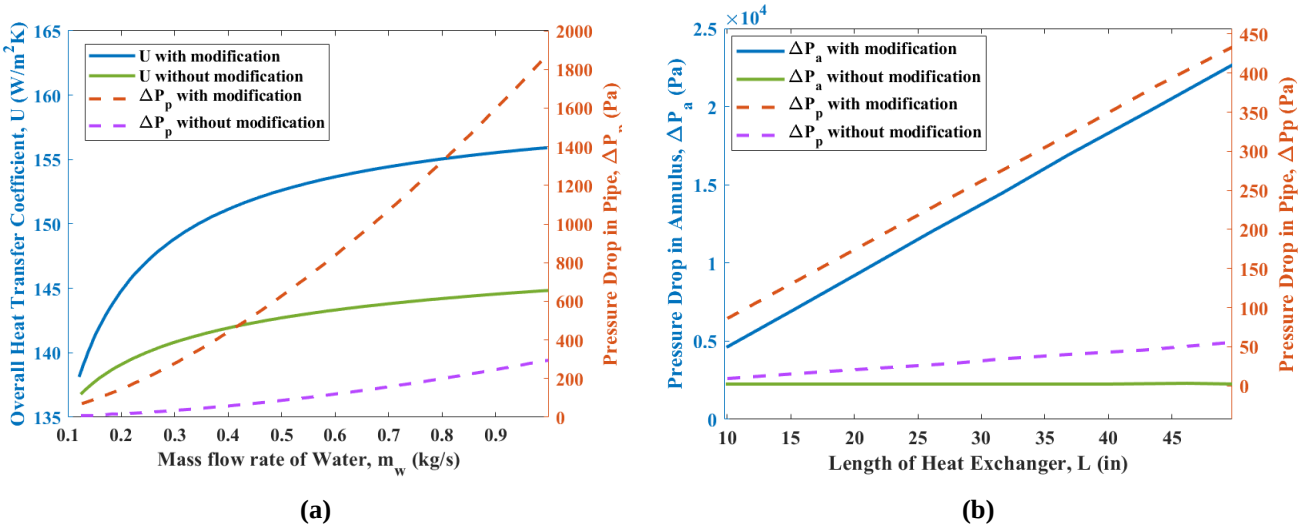


Fig. 2. (a) Variation of overall heat transfer coefficient and pressure drop in pipe with mass flow rate of water for both modified and bare heat exchanger.
(b) Variation of pressure drop in annulus and pipe with length of modified and bare heat exchanger

The mass flow rate of water and heat exchanger length were varied to examine their effects on the thermal and pressure drop characteristics of the DPHXs. As shown in Figure 2(a), the overall heat transfer coefficient (U), which is indicated by solid lines, increases with the mass flow rate of water for both the modified and bare designs. However, the modified heat exchanger (blue solid curve) consistently demonstrates higher values due to the additional surface area provided by the fins and enhanced turbulence from the twisted tape. The pressure drop in the pipe, which is indicated by dashed lines, also rises exponentially with increasing mass flow rate, with the modified heat exchanger (red dashed line) showing a steeper increase due to the higher resistance caused by the fins.

On the other hand, varying the length of the heat exchanger does not affect the overall heat transfer coefficient. Our proposed design has better U due to the added fins and turbulator but neither of the DPHXs show any changes in heat transfer coefficient with variation in size; so not presented here. Figure 2(b) shows that the pressure drop in the pipe (red dashed line) rises more significantly for the modified exchanger, reflecting the impact of increased flow resistance with the longer length.

3.2 Impact of design modifications on the performance of the modified heat exchanger

3.2.1 Number of fins

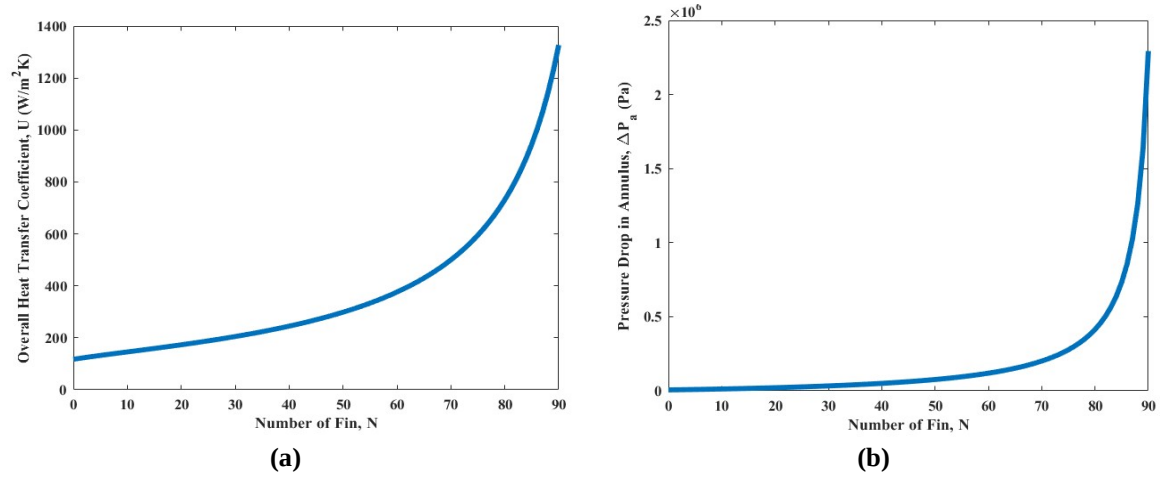
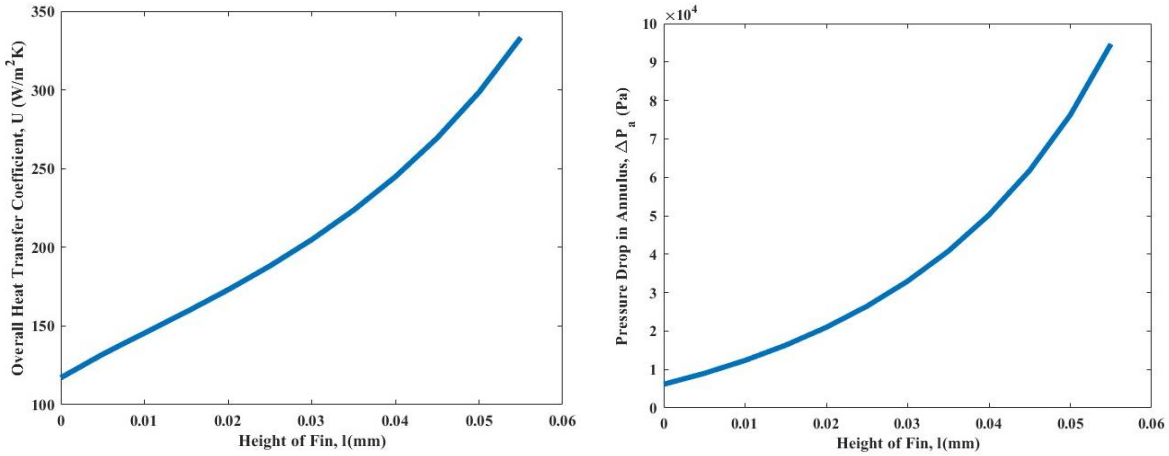


Fig. 3. Variation of (a) overall heat transfer coefficient and (b) pressure drop in annulus with number of fins

As shown in Figure 3(a), the overall heat transfer coefficient increases as the number of fins is increased, owing to the larger surface area for heat exchange. Figure 3(b) shows that the pressure drop in the annulus also rises along with it, since more fins obstruct the flow which increases resistance. However, the fins being in the annular region the pressure drop in the inner pipe is not affected by fins.

3.2.2 Fin height

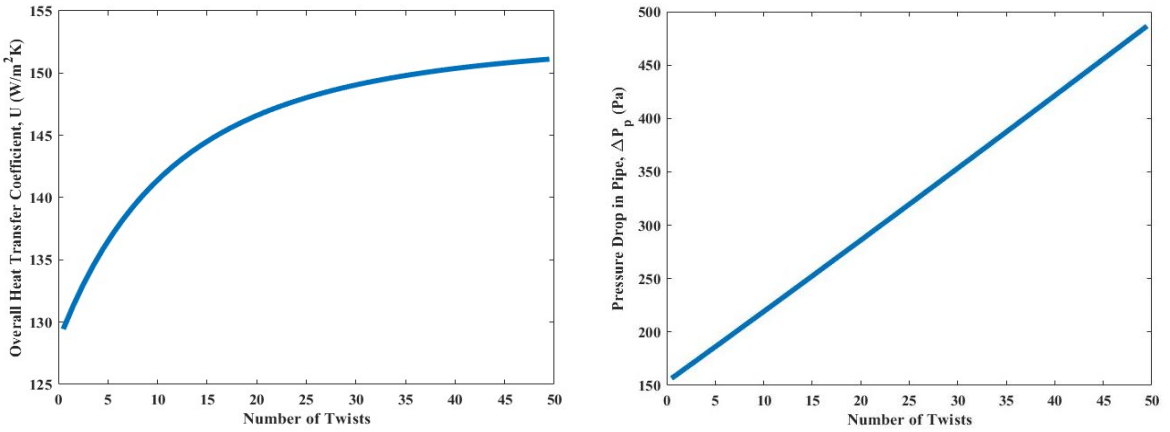


(a) **(b)**

Fig. 4. Variation of (a) overall heat transfer coefficient and (b) pressure drop in annulus with fin height

As shown in Figure 4(a), increasing the fin height improves the overall heat transfer coefficient, as a taller fin provides more surface area so better heat transfer occurs. However, Figure 4(b) shows that the pressure drop in the annulus increases significantly as taller fins introduce more flow resistance and drag.

3.2.3 Number of twists in the turbulator



(a) **(b)**

Fig. 5. Variation of (a) overall heat transfer coefficient and (b) pressure drop in pipe with number of twists in turbulator

As shown in Figure 5(a), increasing the number of twists in the turbulator enhances the overall heat transfer coefficient due to intensified turbulence within the pipe. However, Figure 5(b) shows that the pressure drop in the pipe also rises sharply with more twists, indicating increased flow resistance.

3.3 Key Findings from Performance Comparison

- The modified heat exchanger achieved a heat duty of 645 W, nearly four times higher than the 161 W measured for the bare DPHX which implies improved cooling. (See supplementary materials)
- The overall heat transfer coefficient increased by nearly 10%, highlighting the effectiveness of rectangular fins and a twisted tape turbulator in enhancing thermal performance.
- There was a slight rise in pressure drop, indicating the need for optimization of the design to balance performance and flow resistance.

4. Conclusion

This paper demonstrates that incorporating rectangular fins and twisted tape turbulators in a double pipe heat exchanger significantly enhances its heat transfer performance. The overall heat transfer coefficient shows a notable increase of nearly 10%, highlighting the benefits of these additions. The heat duty is around 4 times higher than bare tube heat exchanger. However, this improvement is accompanied by greater pressure drops, underscoring the need for careful optimization of heat exchanger designs. The findings provide valuable insights for refining heat exchanger models in various industrial applications, including power generation, chemical processing, and HVAC systems, where efficient thermal management is essential. By addressing the trade-offs between improved heat transfer and increased pressure drops, this study lays a foundation for optimizing heat exchanger designs to meet diverse operational requirements. These results pave the way for the development of energy-efficient and cost-effective thermal management solutions, contributing to enhanced performance and sustainability across industries.

5. References

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