

Comparative CFD evaluation of turbulators for enhanced heat transfer in a double pipe counter-flow heat exchangerE.K. Ketter

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Abstract. This study evaluates five turbulator configurations – twisted tape, corrugated tube, conical ring, dimpled tube, and a hybrid design (conical ring + twisted tape) – in a double pipe counter-flow heat exchanger using CFD simulations. The goal is to compare their impact on heat transfer efficiency and pressure loss. The results show that the hybrid turbulator offers the highest thermal performance but also leads to the highest-pressure loss, highlighting the trade-offs engineers must consider when optimizing heat exchanger performance.

Key words: turbulators, heat transfer, double pipe counter-flow, pressure loss.

Introduction

Heat exchangers are vital components in various industrial systems, such as chemical processing, energy production, and HVAC, where efficient heat transfer is crucial [1]. Double pipe counter-flow heat exchangers are commonly used due to their robustness and efficiency [2]. However, laminar flow within the tubes can reduce heat transfer by forming a thermal boundary layer [3].

Turbulators, which are inserts that disrupt flow, are used to induce turbulence, enhance fluid mixing, and reduce the boundary layer, improving heat transfer. Previous research has shown that turbulator designs such as twisted tapes significantly enhance heat transfer by inducing helical flow [4]. Other designs, such as corrugated tubes, dimpled tubes and conical rings, also promote turbulence but may have varying effects on pressure drop [5, 6].

While many turbulator designs exist, there is limited research comparing them under consistent conditions. This study aims to fill that gap by evaluating five turbulator types through CFD simulations to identify the most efficient configurations for enhanced heat transfer.

Research methods

The methodology of this study combines manual calculations and CFD simulations to assess the thermal performance and pressure drop in a double pipe counter-flow heat exchanger incorporating various turbulator configurations. In the manual calculations, a smooth tube serves as the baseline, and key parameters such as the Reynolds number (Re), heat transfer coefficient (α), and thermal power (Q) are determined using fluid properties and tube dimensions [7]. The Reynolds number is computed using Formula (1):

$$Re = \frac{\rho \times \omega \times d_{in}}{\mu}, \quad (1)$$

where ρ is the fluid density, ω is the fluid velocity, d_{in} is the internal diameter of the tube, and μ is the dynamic viscosity. To calculate the heat transfer coefficient, the Nusselt number (Nu) is determined by (2):

$$Nu = 0.023 \times Re^{0.8} \times Pr^n, \quad (2)$$

where Pr is the Prandtl number and n is used to adjust for the direction of heating or cooling. From the Nusselt number, the heat transfer coefficient α is then calculated by (3):

$$\alpha = \frac{Nu \times \lambda}{d_{in}}, \quad (3)$$

where k is the thermal conductivity of the fluid. In the CFD setup, the same geometry is used, with various turbulator configurations, such as twisted tape, corrugated tube, conical ring, and a hybrid (conical ring + twisted tape), added to alter the flow dynamics. SolidWorks Flow Simulation is used for the CFD analysis to simulate fluid flow, heat transfer, and pressure drop under steady-state conditions. The simulations are performed using consistent boundary conditions, including inlet velocity, temperature, and pressure, for all turbulator configurations to ensure a direct comparison between manual and CFD results. The thermal power of the exchanger is 1.8 Kw. The characteristics of the double pipe counter-flow heat exchanger are given in Table 1 below.

Table 1

Characteristics of the double pipe counter-flow heat exchanger

Parameter	Medium	Diameters (mm)	Temperatures (°C)	Pressure (MPa)
Shell side	Cold water	Inner = 45	In = 30 Out = 32	≤ 0.1
Tube side	Hot water	Inner = 20 Outer = 22	In = 45 Out = 36.5	≤ 0.1

Results

Table 2 presents the thermal performance, including mass flow rate, thermal power, heat transfer coefficient, and pressure loss. The results show that the hybrid configuration has the highest thermal power at 3.76 kW, compared to the smooth tube configuration at 1.69 kW. However, the pressure loss for the hybrid configuration is 40 Pa, which is the highest among the configurations.

Table 2

Thermal performance results obtained from simulation in SolidWorks

Tube configuration	Mass Flow Rate (kg/s)	Thermal Power (kW)	Heat Transfer Coefficient (h) ($\frac{W}{m^2 \cdot K}$)	Pressure Loss (ΔP) (Pa)
Smooth tube	0.125	1.694	1.968×10^3	16.13
Twisted tape	0.125	3.134	3.200×10^3	35.000
Corrugated tube	0.125	2.716	2.800×10^3	30.000
Conical ring	0.125	3.395	3.100×10^3	32.000
Dimpled tube	0.125	2.507	2.700×10^3	25.000
Conical ring + twisted tape	0.125	3.761	3.500×10^3	40.000

Fig. 1 illustrates the impact of various tube configurations on thermal power and heat transfer efficiency in a heat exchanger. The thermal power increases along the tube length, with the conical ring + twisted tape combination generating the highest thermal power (3.8 kW), followed by conical ring (3.4 kW) and twisted tape (3.1 kW). The smooth tube shows the lowest thermal power (1.7 kW). The enhanced heat transfer in more complex configurations, such as the twisted tape and conical ring, generates turbulence, improving fluid mixing and surface contact, which boosts heat exchange efficiency. Fig. 1 demonstrates the temperature distribution and flow trajectories, with the smooth tube exhibiting laminar flow and low heat transfer, while configurations like such as the twisted tape, conical ring, and dimpled tube generate turbulence, improving fluid-wall interaction and leading to more efficient heat exchange. The conical ring + twisted tape combination achieves the most uniform temperature distribution, resulting in the optimal heat transfer performance.

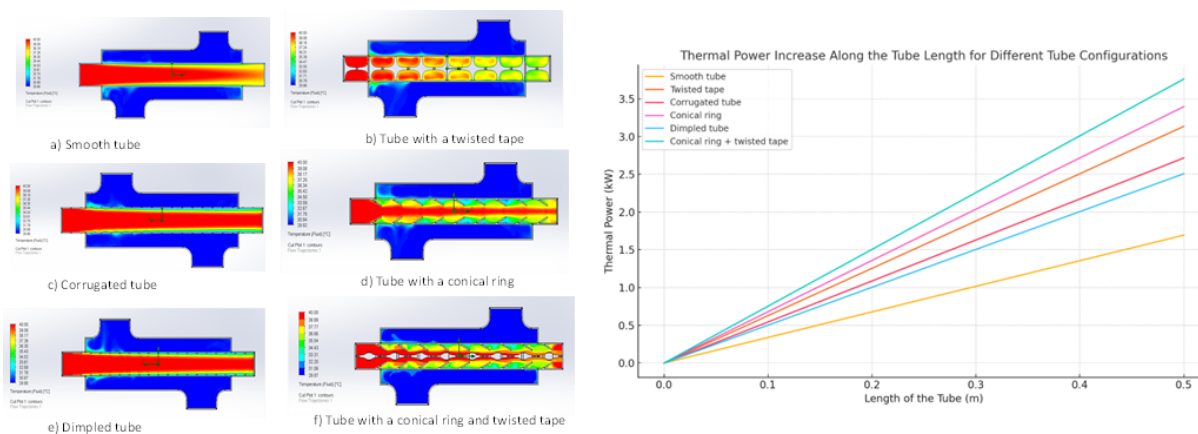


Fig. 1. Thermal power and temperature variation across tube length

Conclusion

In conclusion, the study of turbulator configurations in double pipe counter-flow heat exchangers reveals a trade-off between heat transfer efficiency and pressure loss. Configurations such as twisted tape and conical ring + twisted tape offer the highest thermal performance but result in significant pressure losses. The smooth tube has the lowest pressure drop but compromises heat transfer. The conical ring and twisted tape configurations provide a balance, offering moderate pressure loss with improved thermal performance. The hybrid conical ring + twisted tape delivers the best thermal performance, though at a higher pressure drop. The novelty of this study lies in the identification of the hybrid turbulator (conical ring + twisted tape) as the most effective for heat transfer, highlighting the need for careful turbulator selection based on operational requirements to optimize heat exchanger performance for improved energy efficiency and thermal effectiveness.

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