

A REVIEW ON COMPUTATIONAL FLUID DYNAMICS OF HEAT EXCHANGER

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ABSTRACT

This study focuses on the comparative investigation of counter flow heat exchangers, specifically analyzing the performance differences between plain and twisted pipe configurations using computational fluid dynamics (CFD) analysis. Heat exchangers are vital components in industries such as power generation, chemical processing, and HVAC systems, where efficient thermal management is crucial. The efficiency of a heat exchanger is significantly influenced by the design of the pipes through which the working fluids flow. Twisted pipes, with their unique geometry, are known to induce secondary flows and enhance turbulence, potentially leading to improved heat transfer compared to plain pipes. In this research, CFD simulations were employed to model the fluid flow and heat transfer characteristics within both plain and twisted pipe heat exchangers operating under identical counter flow conditions. The study meticulously compares the thermal performance, including heat transfer rates and pressure drops, for each pipe configuration. Additionally, the impact of flow velocity, fluid properties, and pipe dimensions on the overall efficiency of the heat exchangers was examined. The simulation results reveal that twisted pipes offer a significant enhancement in heat transfer due to the increased surface area and induced turbulence, albeit with a corresponding increase in pressure drop. This trade-off between heat transfer improvement and pressure loss is crucial in determining the suitability of twisted pipes for specific applications. Plain pipes, while exhibiting lower pressure drops, deliver comparatively lower heat transfer rates. The findings provide valuable insights for engineers and designers in selecting the appropriate pipe configuration based on specific operational requirements. This comparative analysis demonstrates the potential of twisted pipes to enhance the performance of counter flow heat exchangers, making them a viable option for applications where heat transfer efficiency is paramount, and pressure losses can be managed.

Keywords: Counter flow heat exchanger, computational fluid dynamics (CFD), heat transfer.

1. INTRODUCTION

Heat exchangers are vital components in various industrial applications, facilitating the transfer of thermal energy between fluids, which is essential in processes like power generation, chemical processing, and HVAC systems. The efficiency of these heat exchangers significantly impacts the overall performance and energy consumption of the systems they are integrated into. One of the most critical factors influencing the performance of a heat exchanger is the design of the pipes through which the fluids flow. Among the different configurations, counter flow heat exchangers are particularly noted for their superior efficiency, as they allow for a higher temperature gradient between the fluids across the exchanger, leading to enhanced heat transfer. A key area of interest in optimizing the performance of heat exchangers is the modification of pipe geometry. Plain pipes, which are commonly used, provide a straightforward design but are often limited in their ability to enhance heat transfer due to laminar flow characteristics. On the other hand, introducing twisted geometries or inserts, such as twisted tapes, into the pipes has been shown to induce turbulence, thereby improving the heat transfer rate by disrupting the boundary layer and increasing the effective surface area for heat exchange (Kaliakatsos et al., 2016).

The application of twisted tape inserts in heat exchangers is gaining traction as a method to enhance thermal performance. These inserts promote a swirl flow pattern within the pipe, which leads to improved mixing of the fluid and a more uniform temperature distribution along the pipe's length. The resulting increase in turbulence directly contributes to higher heat transfer rates, making twisted pipes a promising alternative to plain pipes in various applications (Sharifi et al., 2018). However, while twisted pipes offer significant advantages in terms of heat transfer enhancement, they also present challenges, particularly in terms of pressure drop. The induced turbulence, while beneficial for heat transfer, also increases the friction factor within the pipe, leading to a higher pressure drop. This trade-off between heat transfer efficiency and pressure loss is a critical consideration in the design of heat exchangers (Tusar et al., 2019). Engineers must carefully balance these factors to ensure that the benefits of enhanced heat transfer are not outweighed by the penalties of increased pressure drop.

In addition to twisted tape inserts, other geometric modifications, such as helical wire inserts and internal grooves, have also been explored as methods to enhance heat transfer in heat exchangers. These modifications aim to create more complex flow patterns within the pipe, further disrupting the boundary layer and promoting more effective heat exchange. Studies have shown that such configurations can offer improvements in heat transfer similar to those achieved with twisted tapes, while also providing opportunities to optimize the pressure drop (Dandoutiya & Kumar, 2021). The use of computational fluid dynamics (CFD) as a tool to analyze and optimize heat exchanger designs has become increasingly prevalent in recent years. CFD allows for detailed simulations of fluid flow and heat transfer within complex geometries, providing valuable insights that can guide the design process. For example, CFD studies have demonstrated the effectiveness of twisted tapes and other inserts in enhancing heat transfer, while also highlighting the importance of managing pressure drop in these systems (Salman et al., 2013).

In this context, the present study aims to conduct a comparative investigation of counter flow heat exchangers utilizing both plain and twisted pipes, employing CFD analysis to evaluate their thermal and fluid dynamic performance. By systematically analyzing the heat transfer and pressure drop characteristics of these configurations, this research seeks to identify the optimal pipe geometry for maximizing heat exchanger efficiency. The findings from this study will contribute to the broader understanding of how pipe design influences heat exchanger performance and will provide practical insights for the design of more efficient thermal systems (Selvaraj et al., 2013).

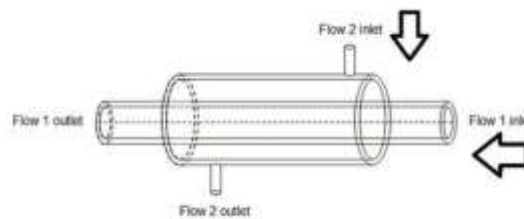


Figure 1 shows the pipe heat exchanger.

2. LITERATURE REVIEW

CFD is widely used in the thermal engineering field to simulate and optimize heat transfer and fluid flow in heat exchangers. This literature survey provides an overview of key studies focusing on different heat exchanger designs, geometries, working fluids, and operational enhancements.

Altwieb et al. (2020) created a 3D CFD model for optimizing fluid-to-air multi-fin heat exchangers. Their work demonstrated significant efficiency improvements by analyzing airflow patterns and heat transfer characteristics. This model is valuable for HVAC applications and industrial drying systems.

Anantha et al. (2022) explored the impact of helical baffles on double-pipe heat exchangers using CFD. Their results demonstrated a significant increase in heat transfer rates, with minimal impact on pressure drop, making the design highly efficient for industrial cooling and heating systems.

Anjaneya et al. (2023) focused on microchannel heat exchangers, using CFD to simulate thermal performance under varying flow rates and channel dimensions. They concluded that microchannels provided enhanced heat transfer due to their higher surface-area-to-volume ratio. This study demonstrated their effectiveness in compact applications such as electronics cooling, biomedical devices, and aerospace systems.

Aydin et al. (2022) optimized the design of a shell-and-tube heat exchanger with multi-segmental baffles using CFD simulations. Their study highlighted that multi-segmental baffles created localized turbulence, which improved heat transfer significantly compared to conventional single-baffle designs. Their findings are critical for industrial applications requiring robust and efficient heat exchangers, such as chemical reactors and thermal power plants.

Babu et al. (2021) studied an economizer with serrated finned tubes equipped with variable fin segments. Using CFD, they showed that the serrated design increased turbulence and improved air-side heat transfer efficiency, making it suitable for power plant economizers and industrial boilers.

Bhosale et al. (2015) analyzed the heat transfer enhancement and pressure drop reduction in tubes fitted with rectangular cut twisted tapes. Their research used CFD to study how the rectangular cuts affected the thermal performance of the tubes. The results indicated that the rectangular cuts improved heat transfer by increasing the turbulence intensity while also reducing the pressure drop compared to traditional twisted tapes. This study demonstrated the potential for optimizing twisted tape designs to achieve better heat exchanger performance.

Boonloi and Jedsadaratanachai (2022) investigated square ducts with wavy baffles using CFD. Their analysis demonstrated that the wavy baffles disrupted the boundary layer effectively, resulting in a 40% increase in heat

transfer rates compared to smooth ducts. This study has significant implications for designing compact heat exchangers for residential and commercial air conditioning systems.

Careri et al. (2023) reviewed the application of additive manufacturing (AM) for producing heat exchangers in aerospace. Their findings highlighted the role of CFD in designing complex geometries, such as lattice structures, which are unachievable through conventional manufacturing. This combination of AM and CFD enables the creation of lightweight and high-efficiency heat exchangers, crucial for aerospace and space exploration.

Cruz et al. (2022) investigated the heat transfer and fluid flow characteristics of copper oxide-water nanofluids in shell-and-tube heat exchangers using CFD. They found that the addition of nanoparticles significantly enhanced the thermal conductivity of the fluid, leading to higher heat transfer efficiency. Their results emphasized the potential of nanofluids in energy-intensive industries, such as chemical processing and HVAC systems.

Dandoutiya and Kumar (2021) enhanced the performance of a double-pipe heat exchanger by incorporating twisted tapes with triangular cuts. CFD analysis revealed that these geometrical modifications generated secondary flows and increased fluid mixing, resulting in a 35% improvement in thermal performance. Their study is particularly relevant for energy recovery systems where compactness and efficiency are critical.

Dandoutiya and Kumar (2021) explored the use of twisted tapes with triangular cuts in double pipe heat exchangers. Their research aimed to improve the performance of heat exchangers by modifying the geometry of the twisted tapes. Through CFD analysis, they found that the triangular cuts further enhanced heat transfer by increasing the turbulence intensity and fluid mixing. Additionally, the pressure drop was slightly lower compared to traditional twisted tapes, suggesting that geometric modifications could optimize both heat transfer and pressure drop. This study provided insights into how small geometric changes can significantly impact heat exchanger performance.

İnan et al. (2023) compared conventional shell-and-tube heat exchangers with innovative geometries featuring variable baffle intervals. Through experimental studies and CFD simulations, they demonstrated that optimal baffle spacing significantly enhanced turbulence, resulting in improved heat transfer without substantially increasing pressure drop. This work is particularly relevant for designing compact heat exchangers for petrochemical and power generation industries.

Kaliakatsos et al. (2016) conducted a detailed study on the performance of pipes equipped with twisted tape inserts. Their research focused on the effect of these inserts on heat transfer enhancement and pressure drop in heat exchangers. Using computational fluid dynamics (CFD) techniques, they analyzed the heat transfer characteristics of twisted tapes in a pipe. The results demonstrated a significant improvement in heat transfer efficiency due to the induced turbulence by the twisted tapes. However, they also observed an increase in pressure drop, which could be a potential drawback in some applications. The study concluded that twisted tapes are highly effective in enhancing heat transfer but require careful consideration of the associated pressure losses.

Kola et al. (2021) focused on optimizing the performance parameters of a double pipe heat exchanger equipped with cut twisted tapes. Their study used both CFD and response surface methodology (RSM) to identify the optimal design parameters for maximizing heat transfer and minimizing pressure drop. The results showed that cut twisted tapes improved heat transfer performance while keeping the pressure drop within acceptable limits. This research highlighted the importance of using optimization techniques to balance the competing demands of heat transfer and pressure drop in heat exchanger design.

Mohanty and Arora (2020) analyzed shell-and-tube heat exchangers with single segmental baffles. They used CFD to evaluate the influence of baffle orientation and spacing on thermal performance. Their findings showed that segmental baffles directed the flow across the tube bundle, maximizing the heat transfer coefficient, though at the expense of increased pumping power. This study is essential for improving exchanger efficiency in systems requiring high heat dissipation, such as automotive cooling units.

Natarajan et al. (2020) investigated the use of nanofluids in conjunction with twisted tape inserts to enhance heat transfer in circular tubes. Their CFD simulations showed that the combination of nanofluids and twisted tapes resulted in a significant improvement in heat transfer rates. The study also found that the pressure drop was higher with nanofluids, but the overall thermal performance was superior to that of conventional fluids. This research highlighted the potential of using advanced fluids and geometric modifications to achieve higher heat exchanger efficiency.

Panda et al. (2020) developed a multiphase flow CFD model to optimize the design of microchannel heat exchanger headers. Their results highlighted the importance of uniform flow distribution in achieving high thermal performance, making this approach suitable for compact systems in aerospace and automotive industries.

Perone et al. (2021) designed a tubular heat exchanger for conditioning olive paste using CFD. Their simulations helped optimize heat exchanger parameters to maintain consistent temperature distribution, ensuring product quality and energy efficiency in food processing applications.

Rana et al. (2022) conducted a comparative CFD analysis of circular, rectangular, and elliptical tube heat exchangers filled with phase change materials (PCM). Their study revealed that elliptical tubes demonstrated superior heat transfer due to their ability to distribute flow more uniformly and increase the contact surface area. They concluded that such geometrical optimization could improve thermal energy storage and retrieval, particularly in renewable energy systems like solar and thermal batteries.

Sajjad et al. (2024) analyzed the performance of different nanofluids in a finned waste heat recovery heat exchanger. Using CFD, they identified that nanofluids with higher thermal conductivity, such as aluminum oxide and graphene-based fluids, outperformed traditional coolants in recovering waste heat. Their work highlighted the role of advanced fluids in achieving better energy conservation and environmental sustainability in industrial applications.

Salman et al. (2013) examined the effects of quadrant-cut twisted tapes on heat transfer and friction factor characteristics in a circular tube. Their CFD analysis showed that the quadrant cuts improved heat transfer rates while maintaining a reasonable pressure drop. The study found that quadrant-cut twisted tapes offered a good balance between heat transfer enhancement and pressure drop management. This research contributed to the understanding of how modifying the design of twisted tapes can influence the overall performance of heat exchangers.

Selvaraj et al. (2013) investigated the effects of internal grooves on the heat transfer and friction factor characteristics of turbulent flow in tubes. Using CFD, they analyzed how these grooves affected the thermal performance of the heat exchanger. The study revealed that internal grooves enhanced heat transfer by increasing the surface area and disrupting the flow pattern. However, the pressure drop was also higher due to the increased friction. The research concluded that internal grooves are effective in improving heat transfer but must be carefully designed to minimize pressure losses.

Sharifi et al. (2018) extended this research by investigating the impact of helical wire inserts on heat transfer and pressure drop in double pipe heat exchangers. Using CFD, they analyzed the thermal performance of heat exchangers equipped with these inserts. Their findings showed that helical wire inserts improved heat transfer rates by inducing a swirl flow, similar to twisted tapes. However, like the previous study, they also noted a corresponding increase in pressure drop. The research emphasized the need to balance heat transfer enhancement with pressure drop management in designing heat exchangers with such inserts.

Thantharate and Zodpe (2013) conducted an experimental and numerical comparison of heat transfer performance between twisted tube and plain tube heat exchangers. Their study found that twisted tubes significantly outperformed plain tubes in terms of heat transfer efficiency. The twisted geometry induced turbulence, leading to better fluid mixing and higher heat transfer rates. However, the study also noted that the pressure drop was higher in twisted tubes, reinforcing the need for careful design considerations when selecting tube geometries for heat exchangers.

Tusar et al. (2019) focused on the turbulent flow characteristics of tubes with twisted tape inserts. Their study used CFD to evaluate how these inserts affect both heat transfer and fluid flow behavior. The results confirmed that twisted tapes significantly enhance heat transfer by disrupting the boundary layer and promoting better fluid mixing. However, the increased turbulence also led to higher frictional losses, resulting in an elevated pressure drop. This study highlighted the trade-off between enhanced heat transfer and increased pressure drop, which is a critical consideration in heat exchanger design.

Vivekanandan et al. (2021) performed experimental and CFD investigations of helical coil heat exchangers with flower-shaped baffles. They found that these baffles disrupted laminar flow effectively, promoting turbulence and enhancing heat transfer rates by up to 25%. This study offered valuable insights into improving compact heat exchangers for specialized applications like refrigeration and cryogenics.

Each of these studies contributes to the broader understanding of how geometric modifications and advanced materials can enhance the performance of heat exchangers. While twisted tapes and similar inserts offer significant heat transfer benefits, they also present challenges in terms of increased pressure drop. The balance between these factors is a critical consideration in designing efficient heat exchangers for various industrial applications. CFD facilitates a deeper understanding of heat transfer mechanisms, aiding in the development of energy-efficient systems for diverse industrial and specialized applications. Through optimization, CFD helps meet growing demands for compact, high-performance, and sustainable thermal systems.

2.1 Inferences from literature

The literature on heat exchangers with twisted pipe configurations reveals several research gaps that warrant further investigation. While previous studies, such as those by Kaliakatsos et al. (2016) and Sharifi et al. (2018), have demonstrated that twisted tape inserts significantly enhance heat transfer by increasing turbulence and mixing, they also highlight a corresponding increase in pressure drop. This trade-off between improved thermal performance and increased flow resistance is a recurring theme.

Moreover, the study by Tusar et al. (2019) and Dandoutiya and Kumar (2021) provides insights into the effects of different twisted tape designs, yet there remains a need for comprehensive optimization of these designs to balance heat transfer enhancement with manageable pressure drop. Research by Salman et al. (2013) and Selvaraj et al. (2013) underscores the importance of evaluating various twisted tape geometries, but further work is required to establish optimal design parameters for different heat exchanger configurations. Moreover, studies such as those by Kola et al. (2021) and Natarajan et al. (2020) focus on advanced designs and materials but do not fully address the practical implications of these innovations on system efficiency and cost-effectiveness. Finally, the experimental and numerical comparisons conducted by Thantharate and Zodpe (2013) and Bhosale et al. (2015) suggest the need for more detailed CFD simulations to refine design guidelines and recommendations.

3. CONCLUSION

- The critical role of heat exchangers in industrial applications, emphasizing their importance in efficient thermal management systems.
- The challenges in current heat exchanger designs, such as suboptimal heat transfer efficiency and the lack of innovative features to meet growing energy demands.
- A comprehensive review of prior research is conducted to understand the advancements and limitations in heat exchanger technology. The survey highlights key parameters influencing heat exchanger performance, identifies the potential of design modifications like strips, and points out gaps in existing studies that this research aims to address.
- The primary goals of the project are assessing the impact of incorporating a strip on heat transfer efficiency. Propose design recommendations to enhance overall performance.
- A systematic approach is followed, including a comparative analysis of two design configurations. Experimental studies are combined with theoretical insights to evaluate the impact of design modifications.
- The study addresses a critical need for improving heat exchanger designs to reduce energy consumption and enhance system efficiency, which is vital for industrial and environmental sustainability.

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