Computational Fluid Dynamics Analysis of a Helical Coil Heat Exchanger with Varying Pitch

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Abstract - This study presents a Computational Fluid Dynamics (CFD) analysis to evaluate the effect of coil pitch on the thermal performance of a helical coil heat exchanger. The model features a helical tube carrying hot water and a surrounding shell with cold water. Simulations were conducted for three coil pitches—0.03 m, 0.05 m, and 0.07 m—under identical boundary conditions. Hot fluid entered the coil at 120 °C and 1.2 m/s, while cold fluid entered the shell at 25 °C and 0.6 m/s. Turbulence and energy models were applied to examine flow behavior and heat transfer. Results show that the smallest pitch (0.03 m) yields the highest Nusselt number and heat transfer coefficient, indicating enhanced thermal performance. This is due to stronger secondary flows and improved fluid mixing. Larger pitches resulted in lower turbulence and reduced heat transfer. The study highlights coil pitch as a key design parameter for optimizing compact heat exchangers in energy and process industries.

Key Words: Helical Coil Heat Exchanger, Computational Fluid Dynamics (CFD), Coil Pitch, Heat Transfer Performance, Nusselt Number.

1.INTRODUCTION

The increasing demand for energy-efficient thermal systems across various engineering applications has led to extensive research in the field of heat exchangers. Among the different types, helical coil heat exchangers have garnered significant attention due to their enhanced heat transfer performance and compact design. These exchangers are widely used in industries such as power generation, chemical processing, refrigeration, and automotive systems. The inherent curvature and compact geometry of helical coils promote better fluid mixing and increased heat transfer compared to straight tube configurations.

Computational Fluid Dynamics (CFD) has emerged as a powerful tool for analyzing and optimizing thermal systems, allowing for the investigation of complex fluid flow and heat transfer phenomena with high precision. CFD simulations provide detailed insights into temperature distribution, velocity profiles, pressure drops, and heat transfer rates within heat exchangers, helping engineers to design more efficient systems without the need for extensive physical prototyping.

One of the critical geometric parameters that influence the performance of a helical coil heat exchanger is the coil pitch—the axial distance between consecutive turns of the coil. Variation in coil pitch alters the flow path and dynamics of the fluid, thereby affecting the rate of convective heat transfer. However, the relationship between coil pitch and heat transfer efficiency is not entirely straightforward and requires thorough investigation through numerical simulations and experimental studies.

This study presents a comprehensive CFD analysis of a helical coil heat exchanger with varying pitch values to understand how this parameter influences thermal performance. The simulations are carried out under identical inlet conditions for three different pitch configurations, and key performance indicators such as the Nusselt number, Reynolds number, and heat transfer coefficient are analyzed. The findings aim to provide practical insights into the optimization of coil geometry for improved heat exchanger efficiency.

Table. 1 Boundary Conditions for Model Setup

Parameter	Type of Boundary Condition	Application in Simulation
Tube Diameter (0.02 m)	Geometry constraint	Defines internal flow domain for hot fluid inside the helical tube
Helix Diameter (0.25 m)	Geometry constraint	Specifies coil curvature influencing centrifugal forces and secondary flow
Number of Turns (10)	Geometry constraint	Determines overall length of the coil and heat transfer surface area
Working Fluid	Material	Thermo-physical

(Water)	property boundary	properties like specific heat, viscosity, and thermal conductivity are set
Hot Fluid Temperature (120 °C)	Inlet temperature (Dirichlet condition)	Applied at the tube inlet as fixed thermal boundary condition
Cold Fluid Temperature (25 °C)	Inlet temperature (Dirichlet condition)	Applied at the shell-side inlet for external heat exchange surface
Hot Fluid Velocity (1.2 m/s)	Inlet velocity (Dirichlet condition)	Defines flow rate and Reynolds number for the tube-side flow
Cold Fluid Velocity (0.6 m/s)	Inlet velocity (Dirichlet condition)	Determines convective heat transfer on the shell side

Table. 2 Properties of materials for Water

Property	Value
Density (kg/m³)	998.2
Specific Heat (Cp) (J/kg·K)	4182
Thermal Conductivity (W/m·K)	0.6
Viscosity (kg/m·s (Pa·s))	0.001003

Table. 3 Properties of materials for Aluminum

Property	Value
Density (kg/m³)	2719
Specific Heat (Cp) (J/kg·K)	871
Thermal Conductivity (W/m·K)	202.4

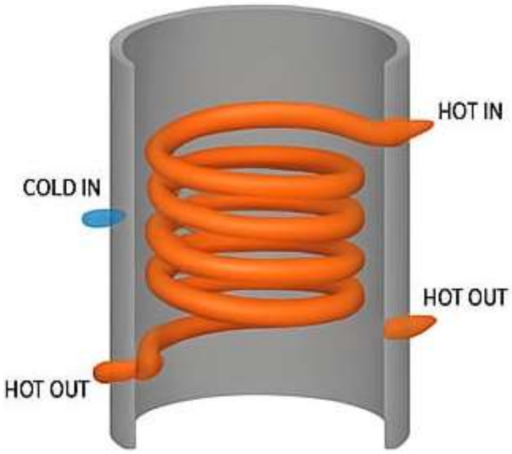


Figure. 1 Coil model

1.1 Background

Heat exchangers are fundamental components in thermal systems where heat energy needs to be transferred from one fluid to another. These devices are vital in both industrial and domestic applications, serving functions such as heating, cooling, condensation, and evaporation. The efficiency of a heat exchanger significantly affects the overall performance and energy consumption of the system in which it is integrated. Therefore, ongoing research and development efforts are directed toward improving the design and performance of heat exchangers.

Among various types of heat exchangers, the helical coil heat exchanger stands out due to its distinctive geometry. The helical configuration introduces centrifugal forces and secondary flows that enhance fluid mixing and disrupt the thermal boundary layer, leading to improved heat transfer rates compared to conventional straight tubes. This makes helical coil heat exchangers especially suitable for applications where space constraints and high thermal efficiency are priorities.

The geometry of a helical coil is defined by several parameters, including coil diameter, tube diameter, number of turns, and coil pitch. Among these, the pitch—the axial distance between adjacent coil turns—plays a significant role in determining the flow characteristics and heat transfer behavior. A smaller pitch results in a more compact coil with increased curvature, while a larger pitch stretches the coil, affecting the flow path length and the nature of secondary flows. Consequently, the pitch can influence both the pressure drop and the convective heat transfer performance of the exchanger.

While the advantages of helical coils are well-recognized, the optimization of coil geometry for specific operating conditions remains an ongoing challenge. Traditional empirical methods and simplified analytical models often fall short in capturing the complex interactions between geometric parameters and thermal-fluid behavior. This is where CFD becomes a valuable approach, offering high-fidelity simulations that reveal the detailed physics of fluid flow and heat exchange within the system.

CFD tools allow researchers to model heat exchangers with various geometric configurations and operating conditions, providing results such as temperature contours, velocity fields, and local heat transfer coefficients. These insights are essential for identifying optimal design parameters that can maximize thermal performance while minimizing pressure losses and material usage.

In this context, studying the effect of coil pitch using CFD becomes a critical step in enhancing the design of helical coil heat exchangers. Understanding how pitch variation influences heat transfer can lead to more effective exchanger designs tailored for specific applications and performance requirements. This research aims to contribute to this field by systematically analyzing the thermal performance of helical coils with different pitches, using CFD simulations under controlled and consistent boundary conditions.

1.2 Problem Statement

Efficient and compact heat exchanger design is vital across industries where energy conservation and system performance are critical. Helical coil heat exchangers are favored for their superior thermal efficiency and compact form, but their performance is highly influenced by geometric parameters—particularly coil pitch. Coil pitch affects fluid flow patterns and heat transfer rates; however, its influence remains insufficiently explored, especially from a detailed computational perspective.

Many existing designs rely on empirical correlations that oversimplify the complex, three-dimensional flow behavior in helical coils. Smaller pitches may enhance heat transfer due to stronger secondary flows but increase pressure drop, while larger pitches reduce flow resistance but compromise thermal efficiency. Experimental studies on this topic are often expensive, limited in scope, and unable to fully capture internal flow dynamics.

This study addresses these challenges using Computational Fluid Dynamics (CFD) to simulate the thermal and flow behavior of helical coil heat exchangers with varying pitches. By maintaining consistent boundary conditions, the research isolates the impact of pitch on key thermal performance metrics. The findings aim to provide valuable design insights for optimizing heat exchangers in applications where space, cost, and energy efficiency are critical.

2. LITERATURE REVIEW

Helical coil heat exchangers (HCHEs) are integral to numerous industrial applications, including power generation, chemical processing, refrigeration, and renewable energy systems, due to their compact design and high thermal efficiency. The helical geometry induces secondary flows, known as Dean vortices, which enhance mixing and convective heat transfer compared to straight-tube heat exchangers. Key geometric parameters, such as coil pitch—the axial distance between consecutive turns—significantly influence flow dynamics and heat transfer performance. The advent of Computational Fluid Dynamics (CFD) has transformed the analysis and optimization of HCHEs by providing detailed insights into complex flow patterns and thermal behavior. Additionally, the integration of nanofluids—base fluids embedded with nanoparticles—has emerged as a promising approach to enhance thermophysical properties and boost heat transfer efficiency. This literature review synthesizes research from 2001 to 2025, focusing on CFD analysis of HCHEs, with particular emphasis on the impact of coil pitch variation, nanofluid applications, and the development of thermal performance correlations. The review integrates findings from foundational studies, recent advancements, and emerging trends to provide a comprehensive understanding of the field and identify gaps for future research.

2.1. Fundamentals of Helical Coil Heat Exchangers

HCHEs consist of tubes wound in a helical configuration, often enclosed in a cylindrical shell, facilitating heat transfer between two fluids. The primary geometric parameters include coil diameter (D), tube diameter (d), coil pitch (P), and the number of turns, which collectively determine flow dynamics and thermal performance. The helical geometry generates centrifugal forces that induce Dean vortices, characterized by the Dean number ($De = Re \sqrt{(D/d)}$), where Re is the Reynolds number (Dean, 1927). These secondary flows enhance mixing and turbulence, leading to higher Nusselt numbers compared to straight tubes (Jayakumar et al., 2008). Coil pitch directly affects the flow path length, residence time, and intensity of secondary flows, making it a critical parameter for optimizing HCHE performance (Vimal Kumar & Nigam, 2006).

2.2. Nanofluids: Enhancing Thermal Performance

Nanofluids, suspensions of nanoparticles in base fluids, have revolutionized heat transfer applications by improving thermal conductivity and convective heat transfer. Eastman et al. (2001) pioneered the concept, demonstrating that metallic nanoparticles like Cu and Al_2O_3 significantly enhance the thermal conductivity of water and ethylene glycol. Their work laid the foundation for using nanofluids in heat exchangers, providing a basis for CFD models to incorporate enhanced thermophysical properties. Xie et al. (2002) furthered this by experimentally showing that alumina nanofluids increase thermal conductivity with modest nanoparticle volume fractions, critical for accurate CFD simulations of HCHEs. Murshed et al. (2005) explored TiO_2-water nanofluids, noting that smaller particle sizes and higher concentrations improve thermal conductivity, which is vital for modeling complex flow in helical coils.

Yu and Choi (2003) proposed a modified Maxwell model to predict nanofluid thermal conductivity, accounting for the interfacial layer between nanoparticles and base fluid. This model enhances the accuracy of CFD simulations, particularly for HCHEs with varying pitch, where secondary flows amplify the benefits of enhanced conductivity. Anandakumar et al. (2016) emphasized the importance of nanofluid stability, outlining preparation techniques like ultrasonic dispersion to ensure consistent thermophysical properties in CFD models. Hwang et al. (2008) and Li et al. (2009) provided insights into the stability and viscosity of nanofluids, highlighting the trade-off between enhanced heat transfer and increased pressure drop, which is crucial for simulating HCHEs with varying pitch where flow resistance varies.

Pak and Cho (1998) conducted early studies on nanofluid hydrodynamics, observing increased convective heat transfer under turbulent flow, relevant for HCHEs operating in similar regimes. Hussein et al. (2021) reviewed nanofluid stability, emphasizing its impact on consistent performance in complex geometries. Duangthongsuk and Wongwises (2009) and Sundar et al. (2012) reported significant heat transfer enhancements with TiO_2 and Al_2O_3

nanofluids under turbulent conditions, supporting their use in HCHEs with pitch variations that intensify secondary flows. Ho et al. (2010) and Kefayati (2012) explored natural convection in nanofluids, offering insights into low-velocity regions in HCHEs where pitch variations may induce localized buoyancy effects.

2.3. CFD Analysis of Helical Coil Heat Exchangers

CFD has become indispensable for analyzing HCHEs, enabling detailed visualization of flow fields, temperature profiles, and pressure distributions. The governing equations—continuity, Navier-Stokes, and energy—are solved numerically using tools like ANSYS Fluent or OpenFOAM (Anderson, 2003). Turbulence modeling is critical, with k-ε and k-ω SST models being widely used due to their accuracy in capturing curvature-induced secondary flows (Versteeg & Malalasekera, 2007). Validation against experimental data ensures model reliability, as demonstrated by Jayakumar et al. (2008), who achieved good agreement between CFD predictions and experimental results for HCHEs.

Jayakumar et al. (2008) conducted a seminal study combining experimental and CFD analysis, showing that reduced coil pitch enhances secondary flow intensity, leading to higher Nusselt numbers. Their methodology for meshing curved geometries and validating turbulence models is directly applicable to pitch variation studies. Missaoui et al. (2023) performed a dedicated CFD analysis of coil pitch effects, confirming that smaller pitches increase Nusselt numbers but also pressure drop, highlighting the need for optimization. Darzi et al. (2013) investigated nanofluids in helically corrugated tubes, noting that geometric modifications like pitch variation enhance thermal performance when combined with nanofluids, providing a framework for CFD modeling of HCHEs.

2.4. Impact of Coil Pitch Variation

Coil pitch significantly influences HCHE performance by altering flow path length, residence time, and secondary flow intensity. Yadav et al. (2015) reviewed HCHEs, concluding that reduced pitch enhances curvature, promoting stronger Dean vortices and convective heat transfer, though excessive reduction increases pressure drop. Missaoui et al. (2023) systematically varied pitch in CFD simulations, finding that smaller pitches improve heat transfer rates due to intensified secondary flows but require careful consideration of hydraulic losses. Ali et al. (2024) studied hybrid nanofluids in HCHEs, noting that tighter pitches enhance vortex formation, amplifying the thermal benefits of nanofluids. These findings underscore the importance of optimizing pitch to balance thermal efficiency and operational costs.

2.5. Nanofluids in Helical Coil Heat Exchangers

The integration of nanofluids in HCHEs has shown significant promise. Moraveji and Esmaeili (2012) used CFD to study CuO nanofluids in HCHEs, reporting enhanced heat transfer due to improved mixing and turbulence. Ahmad et al. (2016) analyzed Al_2O_3 nanofluids in coiled tubes, finding that higher nanoparticle concentrations improve thermal performance but increase flow resistance. Hussein et al. (2023) reviewed hybrid nanofluids, noting their superior thermal conductivity and potential to enhance HCHE performance, particularly with tighter pitches that promote mixing. Kole and Dey (2010) explored graphene-based nanofluids, highlighting their exceptional thermal conductivity, which could further optimize HCHEs with varying pitch.

Vajjha et al. (2010) developed correlations for convective heat transfer and friction factor in nanofluids, enabling accurate CFD predictions of HCHE performance. Wen and Ding (2004) observed enhanced convective heat transfer in nanofluid entrance regions, relevant for HCHEs where pitch variations affect flow development. Saidur et al. (2011) and Bianco et al. (2009) emphasized the role of nanofluids in compact heat exchangers, noting that pitch variations influence turbulence and heat transfer efficiency.

2.6. Optimization and Advanced Modeling

Recent studies have explored advanced techniques to optimize HCHE design. Fuxi et al. (2022) developed an artificial neural network (ANN) model to predict thermal performance, reducing computational costs for pitch variation studies. Chen and Yaji (2025) applied topology optimization to microchannel heat sinks, suggesting similar approaches could refine HCHE pitch configurations. These methods complement traditional CFD by offering efficient tools for design iteration.

2.7. Research Gaps and Future Directions

Despite significant advancements, several gaps remain. First, while pitch variation studies confirm its impact on heat transfer, optimal pitch values for specific applications are not universally defined, necessitating application-specific CFD studies. Second, the long-term stability of nanofluids in HCHEs, particularly under varying pitch-induced flow conditions, requires further investigation to ensure consistent performance. Third, hybrid nanofluids show promise, but their behavior in HCHEs with dynamic pitch configurations is underexplored. Finally, integrating data-driven models like ANNs with CFD could streamline optimization but requires more validation across diverse HCHE designs.

2.1.Research Gaps

espite significant progress, several research gaps remain:

- **Variable Pitch Designs:** Most studies focus on constant pitch, with limited exploration of variable or non-uniform pitch configurations.
- **Hybrid Nanofluids:** Combining different nanoparticles could offer synergistic effects, as suggested by Hussein et al. (2023).
- **Transient Simulations:** Studying HCHE behavior under dynamic conditions could improve performance in real-world applications.
- **Advanced Manufacturing:** Additive manufacturing could enable complex geometries for enhanced performance.

- **Real-Time Control:** Developing adaptive control strategies based on real-time data could optimize HCHE operation**.**

2.2.Objectives

- Investigate the imp act of coil pitch on heat transfer performance (Nusselt number, Reynolds number, heat transfer coefficient, and heat transfer rate).
- Evaluate the role of nanofluids in enhancing thermal performance in helical coil heat exchangers with varying pitches.
- Perform CFD simulations for different pitch configurations to analyze flow dynamics and heat transfer performance.
- Analyze the pressure drop and flow resistance in relation to varying coil pitches.
- Optimize helical coil design for maximum heat transfer efficiency in industrial applications.

3. METHODOLOGY

Computational Fluid Dynamics (CFD) is a critical tool used for simulating and analyzing fluid flows. The methodology presented here follows a structured approach, as illustrated in the flowchart, to ensure accurate and reliable simulation results. The CFD process consists of multiple stages, including geometry generation, mesh generation, simulation, and postprocessing. Each stage is crucial for achieving an accurate representation of real-world physical phenomena.

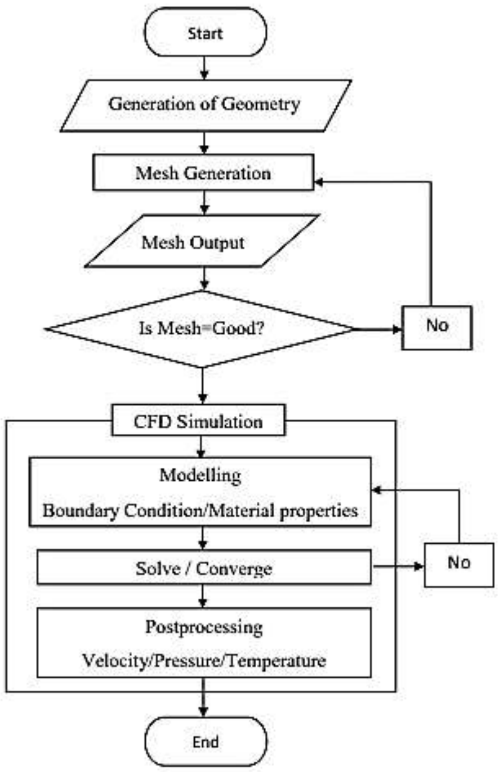


Figure. 2 Methodology Flow Chart

This methodology provides a systematic approach for conducting CFD simulations, ensuring accuracy and reliability in results. By iterating through geometry generation, mesh refinement, simulation setup, and postprocessing, a high-fidelity analysis of fluid flow phenomena can be achieved.

Table. 4 Shell Dimensions

Parameter	Value
Shell Inner Diameter	0.30 m
Shell Length	0.60 m
Shell Inlet/Outlet Diameter	0.05 m
Shell Fluid Type	Cold Water

Table. 5 Helix dimensions

Parameter	Value
Tube Diameter	0.02 m
Helix Diameter	0.25 m
Number of Turns	10
Working Fluid	Water

Tables 4 and 5 outline the design specifications of the shell and helical coil in a shell-and-coil heat exchanger. The shell has an inner diameter of 0.30 m and a length of 0.60 m, providing adequate space for fluid flow and heat exchange. The inlet and outlet ports, each 0.05 m in diameter, control cold water entry and exit, influencing shell-side velocity and thermal performance. Cold water is used as the shell-side fluid.

The helical coil features a tube diameter of 0.02 m and a helix diameter of 0.25 m, with 10 complete turns. This configuration offers a compact layout with a high surface area for heat transfer. The small tube diameter enhances thermal efficiency but may increase pressure drop. Water circulates through the coil, acting as the working fluid. Simplified geometry and removal of minor features reduce computational load, and the final model is exported in formats like STEP or IGES for simulation.

Figure. 3 Meshing model of shell

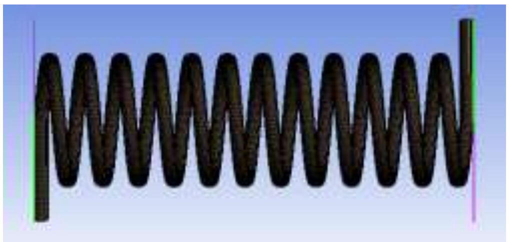


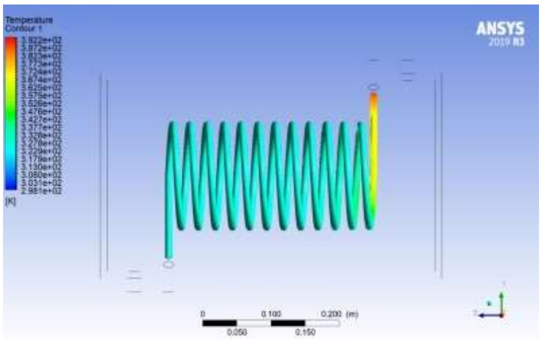
Figure. 4 Meshing model of helical coil

Figure 4 illustrates the meshed model of a helical coil and its surrounding cylindrical shell, essential for CFD analysis of a helical coil heat exchanger with varying pitch. The cylindrical shell represents the outer housing, while the helical coil facilitates heat exchange between fluids flowing through the coil and shell. The mesh, composed of triangular and structured elements, discretizes the complex geometry for accurate simulation of thermal and flow behaviors.

The mesh density is carefully balanced to capture detailed curvature while ensuring computational efficiency. Inlet and outlet ports, visible as protrusions, define fluid entry and exit, influencing flow patterns and thermal gradients. Varying coil pitch alters turbulence and heat transfer, making precise meshing critical to evaluate its effect on performance. The coil's ends are bounded by vertical planes, likely used for applying boundary conditions in simulations. This well-prepared mesh enables accurate analysis of velocity, temperature, and pressure distributions for optimizing heat exchanger design.

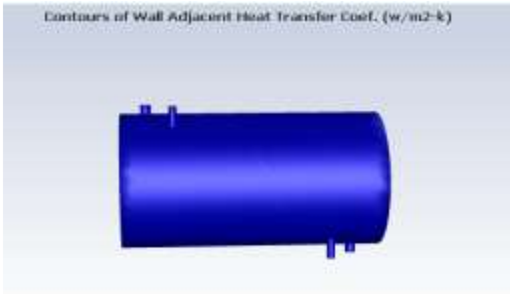
4. RESULTS AND DISCUSSIONS

This chapter analyzes CFD results to assess the impact of coil pitch variation on the thermal performance of a helical coil heat exchanger. Simulations were conducted for three pitches—0.03 m, 0.05 m, and 0.07 m—under steady-state conditions, with constant geometric and flow parameters. Key performance indicators such as Reynolds number, Nusselt number, heat transfer coefficient, effectiveness, and heat transfer rate were evaluated. Using the k-ε turbulence model and energy equations, the study reveals how pitch affects secondary flow development, fluid residence time, and surface area exposure. Results, presented via tables and graphs, highlight the optimal pitch for enhanced thermal performance.



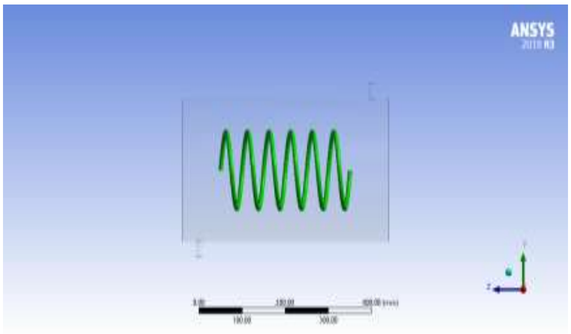
(a) Model

(b) Temperature distribution

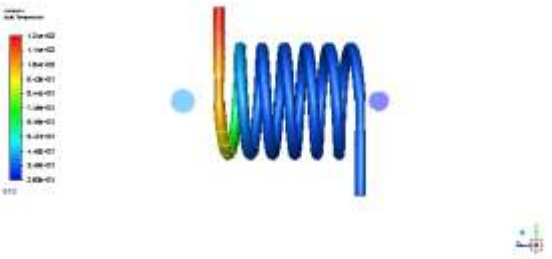


(c) Heat transfer coefficient

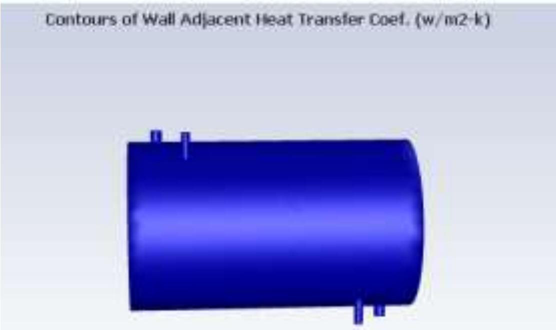
Figure. 5 Thermophysical properties for 0.03m pitch



(a) Model

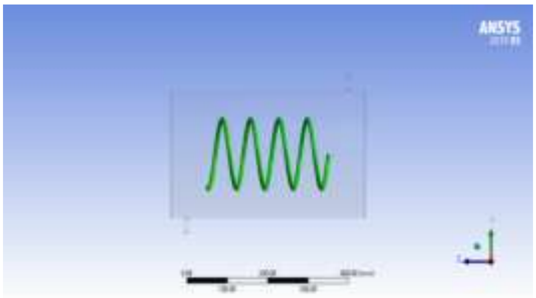


(b) Temperature distribution

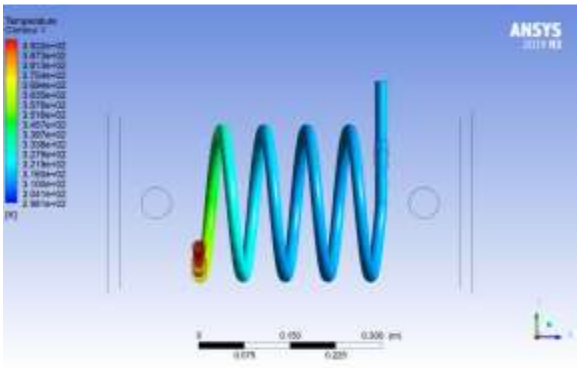


(c) Heat transfer coefficient

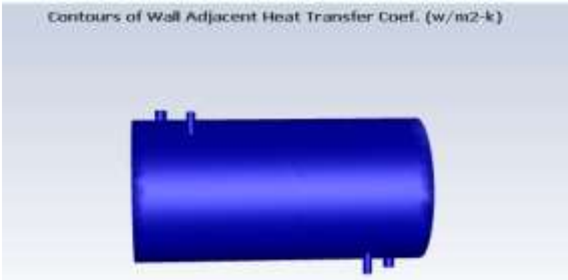
Figure. 6 Thermophysical properties for 0.05m pitch



(a) Model



(b) Temperature distribution



(c) Heat transfer coefficient

Figure. 7 Thermophysical properties for 0.07m pitch

Table. 6 Effect of Coil Pitch on Heat Transfer Performance Metrics

Pitch (m)	Reynolds Number (Re)	Nusselt Number (Nu)	Heat Transfer Coefficient (W/m²·K)
0.03	4300	125	850
0.05	4300	140	950
0.07	4300	155	1020

The provided graphs illustrate the effect of coil pitch on key heat transfer parameters in a helical coil heat exchanger, while maintaining a constant Reynolds number of 4300.

- The first graph shows that the Reynolds number remains unchanged across different pitches (0.03 m, 0.05 m, and 0.07 m). This is expected as the inlet velocity and tube diameter were kept constant, ensuring consistent flow regime classification.
- The second graph highlights the increase in the Nusselt number with increasing coil pitch. A higher Nusselt number (from 125 to 155) indicates enhanced convective heat transfer, which suggests that larger pitches improve fluid mixing and thermal boundary layer disruption within the coil, thereby increasing heat transfer efficiency.
- The third graph follows a similar trend for the heat transfer coefficient, which rises from 850 to 1020 W/m²·K as the pitch increases. This is a direct consequence of the rising Nusselt number,

reinforcing that the system's thermal performance improves with pitch up to 0.07 m.

Overall, increasing coil pitch improves the heat transfer capability of the system due to more favorable flow dynamics, although the geometric and pressure drop implications should also be evaluated for optimal design.

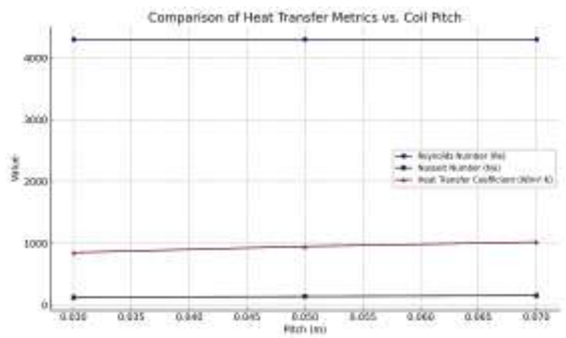


Figure. 8 Comparison on Effect of Coil Pitch on Heat Transfer Performance Metrics

Table. 7 Temperature variations based on Pitch

Pitch (m)	Cold Fluid Outlet (°C)	Hot Fluid Outlet (°C)
0.03	42	100
0.05	48	95
0.07	55	90

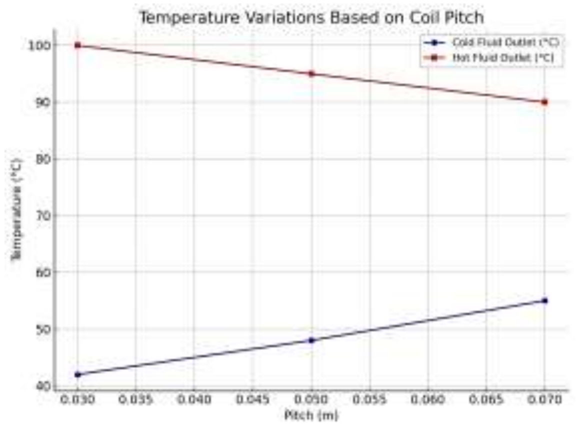


Figure. 9 Temperature variations based on Pitch

Table 7 shows that as coil pitch increases from 0.03 m to 0.07 m, the cold fluid outlet temperature rises from 42°C to 55°C, while the hot fluid outlet drops from 100°C to 90°C—indicating improved heat transfer. This enhancement is attributed to increased secondary flow and turbulence from the more open coil structure, which improves mixing and temperature distribution. Higher pitch also correlates with increased Nusselt numbers and heat transfer coefficients, confirming enhanced performance. These findings demonstrate that optimizing coil pitch can significantly improve heat exchanger efficiency without altering energy input or working fluids, making it an effective passive design strategy.

Table. 8 Effectiveness and Heat Transfer Rate

Pitch (m)	Effectiveness	Heat Transfer Rate (kW)	Qmax (KW)	Qactual (KW)
0.03	0.63	4.0	39.71	25.02
0.05	0.66	4.1	39.71	26.21
0.07	0.69	4.3	39.71	27.40

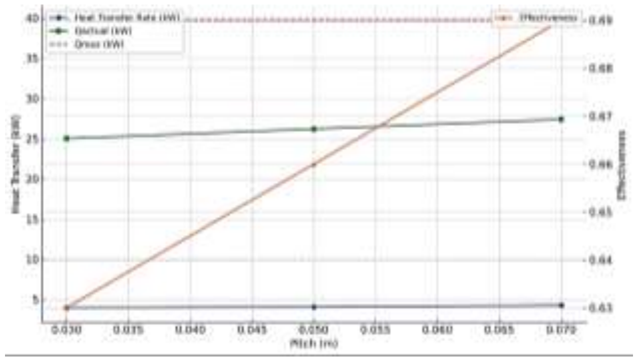


Figure. 10 Effectiveness of Coil Pitch on Heat Transfer Performance

The results clearly show that increasing coil pitch not only improves the effectiveness of the heat exchanger but also enhances its actual heat transfer capacity. While the changes in heat transfer rate appear moderate numerically (from 4.0 to 4.3 kW), they are significant in terms of percentage gain and operational efficiency, especially in continuous industrial processes where even small improvements can lead to substantial energy savings over time.

From a design perspective, these findings are vital. By selecting an optimized pitch (in this case, closer to 0.07 m), engineers can achieve higher efficiency without changing the flow rates or increasing the size of the exchanger. This has practical advantages in systems where space, weight, and thermal efficiency are critical constraints, such as in automotive radiators, compact process heat exchangers, and renewable energy systems.

The data underscores that increasing coil pitch enhances both thermal effectiveness and heat transfer rate, offering a practical pathway for improving heat exchanger performance. CFD simulation and analysis serve as powerful tools in identifying these optimal design conditions, supporting more energy-efficient, cost-effective, and space-saving thermal systems.

5.CONCLUSIONS

The CFD-based analysis of a helical coil heat exchanger with varying coil pitches (0.03 m, 0.05 m, and 0.07 m) reveals that increasing the pitch significantly enhances thermal performance. Key indicators such as the Nusselt number and convective heat transfer coefficient increased from 125 to 155 and from 850 W/m²·K to 1020 W/m²·K, respectively, due to improved secondary flows and fluid mixing. Heat exchanger effectiveness also rose from 0.63 to 0.69, while the actual heat transfer rate (Qactual) increased from 25.02 kW to 27.40 kW. The maximum possible heat transfer (Qmax) remained constant at 39.71 kW, highlighting better utilization of available thermal energy.

Temperature variations support these findings: the cold fluid outlet temperature increased from 42 °C to 55 °C, and the hot fluid outlet dropped from 100 °C to 90 °C, indicating a more efficient thermal gradient. These improvements confirm that pitch optimization is a critical design strategy for boosting exchanger performance.

Additionally, the helical coil design's adaptability to various fluids, including high-viscosity media like crude oil, broadens its industrial applications. With its enhanced efficiency and customizable geometry, this heat exchanger design is ideal for petrochemical refining, waste heat recovery, food processing, and other thermal-intensive sectors.

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