# INFLUENCE OF INNER PIPE GEOMETRIC CONFIGURATIONS ON HEAT TRANSMISSION IN DIVERSE HEAT EXCHANGER SYSTEMS

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**Abstract:** *The research involves a systematic analysis of various inner pipe geometries, such as helical, spiral, ribbed, and smooth configurations, within different types of heat exchangers. Computational simulations, experimental studies, and performance evaluations are employed to assess the thermal characteristics, pressure drops, and overall efficiency associated with each geometric variation. Findings reveal significant variations in heat transmission capabilities based on inner pipe geometry, influencing factors such as turbulence, fluid flow patterns, and thermal boundary layers. The study provides insights into the trade-offs between enhanced heat transfer and pressure drop, guiding the selection of optimal inner pipe configurations based on specific application requirements. This research contributes valuable knowledge to the field of heat exchanger design, offering practical implications for engineers, researchers, and practitioners seeking to improve heat transfer efficiency and overall performance in diverse heat exchanger systems.*

**Keywords:** *Solar drying, Heat Exchanger Technologies, Computational Thermal Fluid Dynamics, Thermal Management, Predictive Modeling.*

## 1. INTRODUCTION

The efficiency of heat exchanger systems plays a pivotal role in various industrial processes, energy systems, and HVAC applications. One crucial aspect influencing their performance is the inner pipe geometric configurations within these heat exchangers. The intricate design and arrangement of inner pipes significantly impact heat transmission and, consequently, the overall thermal efficiency of the system.Understanding the influence of inner pipe geometric configurations is essential for optimizing heat exchanger performance across diverse applications. This research delves into the intricate interplay between geometric factors such as tube diameter, pitch, and arrangement, and their impact on heat transfer mechanisms. By investigating how these configurations affect fluid flow, turbulence, and heat conduction, we aim to uncover key insights that can lead to the enhancement of heat exchanger efficiency. As industries strive for increased energy efficiency and sustainability, a comprehensive exploration of the influence of inner pipe geometric configurations becomes imperative. This study not only contributes to the fundamental understanding of heat transfer phenomena but also provides valuable guidance for engineers and designers seeking to optimize heat exchanger systems for specific applications[1]–[6].

Through empirical analysis and computational modeling, we aim to identify optimal geometric configurations that can lead to improved heat transmission, reduced energy consumption, and enhanced overall performance of diverse heat exchanger systems. The findings of this research have the potential to impact a wide range of industries, offering valuable insights for the design and optimization of heat exchangers in various thermal management applications. Innovations in materials science play a pivotal role in enhancing heat exchanger performance. This review will scrutinize the development and application of novel materials with superior thermal conductivity, corrosion resistance, and mechanical strength[7]–[11].

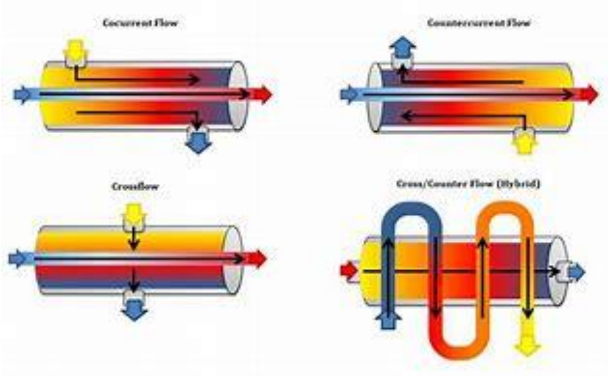

**Figure 1 Basic Heat Exchanger**

Additionally, the exploration of unconventional geometries, such as micro-scale and finned-tube heat exchangers, will be examined for their potential to optimize heat transfer efficiency and compactness. The integration of computational tools, artificial intelligence, and machine learning in heat exchanger design and optimization represents another frontier in technological progress. By leveraging these advanced methodologies, researchers and engineers can expedite the development process, improve accuracy in predicting heat exchanger performance, and explore innovative design solutions that were once deemed impractical [12]–[15].

Moreover, the global emphasis on sustainability has prompted a reevaluation of heat exchanger technologies to align with eco-friendly principles. This review will investigate the efforts made to enhance energy efficiency, reduce environmental impact, and foster a circular economy approach within the realm of heat exchanger design and operation. As we embark on this critical review journey, the overarching goal is to provide a comprehensive understanding of the current state of heat exchanger technologies, offering insights that will inspire future innovations and drive the industry towards more sustainable, efficient, and resilient thermal energy exchange solutions. Compact heat exchangers, including microchannel and printed circuit designs, are investigated for their potential to achieve higher efficiency through increased surface area-to-volume ratios. The integration of enhanced heat transfer techniques, such as surface roughening and vortex generators, is examined to optimize heat exchanger performance. Additionally, the paper delves into the evolving landscape of heat exchangers within renewable energy systems, emphasizing their role in sustainable practices[16]–[19].

Challenges, including fouling, corrosion, and manufacturing complexities, are discussed, and potential solutions are explored. The paper concludes by emphasizing the importance of interdisciplinary collaboration, considering environmental considerations, and prioritizing research efforts towards sustainable, energy-efficient, and adaptable heat exchanger technologies. This critical review serves as a valuable resource for researchers, engineers, and practitioners seeking insights into the latest developments in the field of heat exchanger technologies.

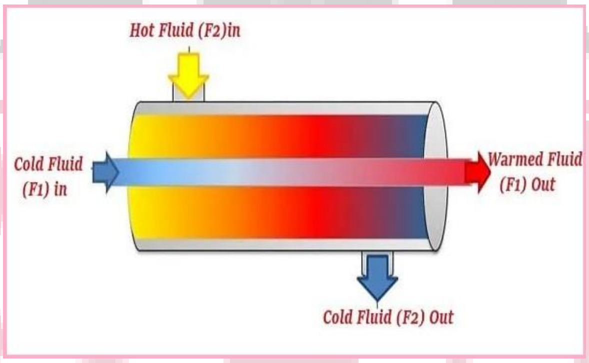

**Figure 2 Configuration-of-Double-Pipe-Heat-Exchangers**

## 2. LITERATURE REVIEW

In a study by Richard et al. [1], a new approach using Computational Thermal Fluid Dynamics (CtFD) was introduced for examining a meander-flow path (MF) fin-type heat exchanger (HX). This was specifically intended for HTS current leads in the LTS coils of the W7-X stellarator and the JT-60SA tokamak. Experiments on an HX mock-up were carried out at the Karlsruhe Institute of Technology, which served as a basis for verifying the accuracy of the computational model. The study began with the hydraulic assessment of the mock-up, followed by an investigation into its heat transfer properties.

In research conducted by Sterkhov et al. [2], the focus was on modernizing the existing steam-power units using a gas turbine combined cycle (CCGT) incorporating a pressurized heat recovery steam generator (PHRSG). The study reveals that such a scheme aligns with the stipulations of the energy development program. One significant advantage is the cost-saving aspect, as it allows for the retention of some equipment components. Through a heat transfer analysis, the team demonstrated the feasibility of simulating the heat exchange process using boiler design software. They found that the ideal flue gas pressure within the PHRSG is around 4–5 bar. Increasing the flue gas pressure to this range maximizes the heat transfer coefficient. Simultaneously, this pressure range is also where the most significant reduction in metal usage is observed.

In a study by Lin et al. [3], a unique model for predicting heat load was introduced, leveraging the hybrid spatial-temporal attention long short-term memory (STALSTM). Their findings highlight that the STALSTM model outperforms others in terms of prediction accuracy. Furthermore, the study underscores the value of integrating spatial-temporal characteristics and the attention mechanism.

Plis et al. [4] crafted a model grounded in the equations of mass and energy balances, paired with empirical ties that chart the heat transfer process and working fluid's pressure drop within the heat exchanger. They determined empirical coefficient unknowns utilizing operating data through the least-squares method. The model not only computes no measured operational parameters and energy evaluation indicators but is also flexible enough to accommodate the evolving technical conditions of the HRSG. They then juxtaposed the model's calculations with actual measurement outcomes. The precision of the model was affirmed through metrics such as the determination factor and the root mean square error.

Sauciuc et al. [5] explored the potential of phase change systems, particularly vapor chambers, to curtail the spreading resistance found in the base of heat sinks. Given that significant advancements remain elusive, there's an urgency to discern the boundaries of limitations for phase change-heat spreaders in CPU cooling, and stack up their efficacy against solid metals with high thermal conductivity. The team introduced two foundational models to clarify heat transfer constraints in phase change systems. Leveraging these models, one can estimate the comparative spreading resistance between phase change systems and solid metals.

In a study led by Khan et al. [6], a one-dimensional mathematical representation of fins encompassing convective, conductive, and radiative elements is proposed. The formulated approach employs the function-approximation prowess of Legendre polynomials integrated with artificial neural networks (ANNs), the global search optimization potential of the Whale Optimization Algorithm (WOA), and the local search precision of the Nelder-Mead algorithm. Comparing the experimental findings with contemporary techniques underscores the superiority of this method. They found that the accuracy of temperature approximation was influenced by the values of Nc, Nr, and λ. The efficacy of the LeNN-WOA-NM algorithm's solutions were further confirmed using metrics like absolute errors, MAD, TIC, and ENSE.

Sixel et al. [7] introduce an innovative application of three-dimensional printed direct winding heat exchangers (3-D-DWHX) aiming to enhance the stator's thermal management in high power density electrical machines. This 3-D-DWHX maintains direct touch with stator windings, leading to heightened continuous current densities. This translates into an elevated continuous power rating and power density. In a nonencapsulated motorette test, a polycarbonate-aluminum flake 3-D-DWHX achieved significant results. Finite element studies indicated even more promising results for encapsulated versions in terms of current density and hotspot temperatures, resulting in a commendable continuous specific power.

In research by Coble et al. [8], the focus was on analyzing the calorimetric dynamics across the intermediate heat exchanger, aiming for real-time primary flow rate inference. Applying heat balance equations to a designed forced flow loop validated the potential of this technique. Factoring in relevant time lags and heat losses, they successfully inferred the primary flow rate with admirable accuracy, as backed by the prediction variance and mean value data.

Liu et al. [9] delve into the architectural design of a cryogenic box, covering aspects such as vacuum system design, refrigerator choice, heat exchanger design, and material selection. Their calculations reveal a thermal load of 25.09 W during the typical operation of the HTS maglev vehicle, which is well within the 120 W cooling capacity of the cryogenic system functioning at 65 K. This affirms the viability of the cryogenic system, potentially serving as a blueprint for future HTS maglev vehicle projects.

Gai et al. [10] examine the integration of an oil-based shaft cooling system in a high-speed automotive traction motor. Initial analyses determine iron and air friction losses across varied speeds. To gauge the system's thermal behavior, they employ both analytical and numerical methods for steady-state and dynamic conditions. Empirical tests are executed to understand key cooling system parameters. Prototype simulations and tests indicate the shaft's rotational speed augments heat exchange efficacy within the coolant and the hollow-shaft's internal surface. Nevertheless, the influence of high rotational velocities diminishes at around 30,000 r/min due to flow saturation.

In research by Qing et al. [11], an exhaustive analytical model that factors in unique temperature-dependent properties and the effective heat transfer coefficient (EHTC) for both-side heat exchangers is formulated. This model aims to scrutinize the intrinsic and extrinsic dynamics of the TEG. Their findings pinpoint certain behaviors relating to optimal load ratio, cold-side EHTC, and hot-side EHTC. Furthermore, they shed light on the optimal dimensions and cross-sectional area ratio of TE components.

Ahmand et al. [12] introduce a pioneering neuroevolutionary algorithm that synergizes the capabilities of feed-forward artificial neural networks (ANNs) and the advanced metaheuristic, Symbiotic Organism Search (SOS) algorithm. Their analysis relies on several performance indicators, such as RMSE, AE, GD, MAD, NSE, and ENSE. The assessment, both statistical and visual, suggests their method's aptness for real-world applications. When juxtaposed with benchmark solutions, their methodology emerges as notably superior.

Pearson et al. [13] delve into a comprehensive design overview, encompassing a preliminary assessment of the tritium breeding ratio (TBR) using neutronics analysis. They also discuss the current status of research and development pertinent to SCYLLA©.

In research led by Kuppusamy et al. [14], they conduct an experimental study on the innovative Triple Fluid Heat Exchanger (TFHEX) designed for heat management in hybrid cooled servers. The TFHEX, characterized by its finned double-tubed design, employs two liquid mediums (hot and warm water) and a gaseous medium (hot air). While some disparities were noted between the experimental and analytical findings, the outcomes suggest that the TFHEX offers the adaptability to handle heat from diverse fluids in varying proportions. This makes it a promising solution for data centers operating in warmer environments.

Chitali et al. [15] executed a detailed three-dimensional conjugate forced convection heat transfer examination on a range of shell-and-tube counter-flow microchannel heat exchangers. Through their investigations of various cross sections (including circular, square, and those with radial ribs), they determined that the circular cross section with radial ribs yielded the most consistent temperature distribution and optimal heat transfer. To achieve maximum efficiency in such heat exchangers, one should factor in these insights during a multi-objective constrained optimization process, especially when contemplating the additive manufacturing of these compact units.

Jung et al. [16] embarked on a study with the objective of elucidating the thermal and pressure drop properties of plate heat exchangers, emphasizing the importance of design factors like channel spacing. Their numerical analyses in relation to flow patterns and channel spacing revealed consistent patterns in the j factor based on the flow rate and channel space. Similarly, they noted a systematic reduction in the f factor with an increase in the mass flow rate.

Khaled et al.[17] examined the potential of using a counter flow concentric tube heat exchanger to harness heat from generator exhaust gases. This captured heat is then utilized to warm water. The most effective setup involved water circulating in the inner tube with a diameter ratio (inner to outer) of 0.75, achieving an average waste heat recovery rate of 26 kW.

Lie et al.[18] created a comprehensive experimental system to assess the heat transfer properties of a heat exchanger. This system boasts automated features, precision in measurements, user-friendly operation, and adaptability. By implementing the Wilson Method to manage experimental data and create fit curves, they derived an empirical equation. This equation closely mirrors traditional ones and proves useful in designing heat exchangers.

Salameh et al.[19] explored the properties of three different nanofluids based on CuO and TiO2, testing various volume fractions and mass flow rates. Using computational fluid dynamics (CFD), they simulated the behavior of each nanofluid at a volume fraction of 0.2%. Their simulations revealed that the CuO nanofluid outperformed the others, with a heat transfer increase of 61%, while experimental data indicated a 50% increase at a 0.05% volume fraction and 62% at a 0.2% volume fraction for CuO.

Raffaele et al.[20] introduced an innovative simulation tool crafted for precise evaluations and designs of single- and multi-passage plate heat exchangers under steady conditions. This tool, grounded in a local one-dimensional effectiveness-NTU method combined with established techniques for determining heat transfer coefficients and pressure drops, is versatile across different conditions, plate designs, and working fluids. An in-depth sensitivity assessment further highlighted the impact of chevron angles and corrugation aspect ratios, leading to the development of a performance index for plate heat exchangers that encompasses both heat duty and pressure drop.

## PROPOSED METHODOLOGY

### Numerical Methods in Heat Conduction

While we are considering simple heat conduction applications that consist of simple geometries with simple boundary conditions, which are easier to solve analytically. But in practical day-to-day applications, we come across various complex geometries and complex boundary conditions or variable properties which are very difficult to solve analytically in such cases accurate approximate solutions can be obtained by using computers with numerical methods. Analytical solution methods are applied by solving the governing differential equation concerning the boundary conditions these results in solution function for the temperature at every point of the medium. Whereas, on another hand numerical method are applied by replacing differential equations by a set of n algebraic equations for the unknown temperature at n selected points in the medium, solutions of these equations results in temperature values at those discrete points.

### Importance of Numerical Methods

The mathematical formulation of a one-dimension study state condition in a sphere of radius $r_0$ where the outer temperature is T1 with uniform heat generation at a rate of $\dot{g}_0$

$$\frac{1}{R^2}\frac{d}{dr}\left(r^2\frac{dT}{dt}\right)+\frac{\dot{g}_0}{k}=0 \qquad (1)$$

$$\frac{dT(0)}{dt}=0 and T r_0=T_1 \qquad (2)$$

$$T_r=T_1+\frac{\dot{g}_0}{6k}(r_0^2-r_0) \qquad (3)$$

### Framework

A mathematical model is applied for a numerical solution is mostly represents the actual problem better. Therefore, the numerical solution of engineering applications has a better solution than expecting analytical solutions.

### Flexibility

While observing engineering problems, we often require more parametric study to understand some variables on the solutions to obtain the right set of variables..

### Modelling

### Geometry of Finite Element Model

Conditions set were a flow rate of 0.1 kg/sec, turbulent intensity of 5%, and a turbulent viscosity ratio of 10 to study the heat transfer.

Geometric Properties

The material is build using the below geometric properties for double pipe heat exchanger.

Table 1: Geometric properties for numerical model.

| S.no | Parameters | Values/Specimen | SI units |
|---|---|---|---|
| 1 | Metal | Copper | Cu |
| 2 | Pipe external diameter | 100 | mm |
| 3 | Pipe internal diameter | 90 | mm |
| 4 | Thickness of the pipe | 10 | mm |
| 5 | Length of the pipe | 3250 | mm |

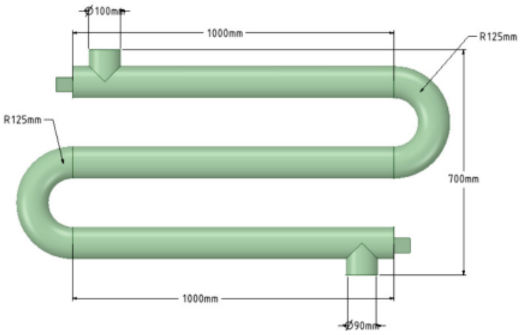

Figure 2: Diagrammatic representation of dimension from numerical modelling

The model is build using the above geometric parameter for dent

Table 2: Geometric properties for numerical model. model

| S.no | Parameters | Values/Specimen | SI units |
|---|---|---|---|
| 1 | Metal | Copper | Cu |
| 2 | Length of innertube | 750 | Mm |
| 3 | Dent size | 2 | Mm |
| 4 | Diameter of inner pipe | 16.5 | Mm |
| 5 | Length of external pipe | 450 | Mm |

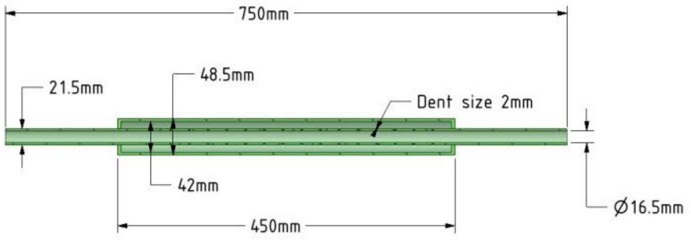

Figure 3: Diagramic representation of dimension from dent model

Material properties

The specimen used to build this numerical model is copper, below are the material properties of the specimen

Table 3: Material properties of numerical model for copper.

| S.no | Parameters | Values/Specimen | SI units |
|---|---|---|---|
| 1 | Density(copper) | 8960 | kg/m3 |
| 2 | Specific heat(copper) | 376.812 | j/kg-k |
| 3 | Thermal conductivity(copper) | 394 | w/m-k |

Table 4: Material properties of numerical model for brass.

| S.no | Parameters | Values/Specimen | SI units |
|---|---|---|---|
| 1 | Density(Brass) | 8730 | kg/m3 |
| 2 | Specific heat(Brass) | 920 | j/kg-k |
| 3 | Thermal conductivity (Brass) | 109 | w/m-k |

Table 5: Material properties of numerical model for Ethanol.

| S.no | Parameters | Values/Specimen | SI units |
|---|---|---|---|
| 1 | Density(Ethanol) | 790 | kg/m3 |
| 2 | Specific heat(Ethanol) | 2470 | j/kg-k |
| 3 | Thermal conductivity (Ethanol) | 0.182 | w/m-k |
| 4 | Mass Flow | 0.1 | Kg/sec |

## RESULTS

### Influence of heat transfer in the presence of triangular inner pipe.

In this study, a double pipe heat exchanger featuring a triangular inner pipe was designed to analyze heat transfer across its length.

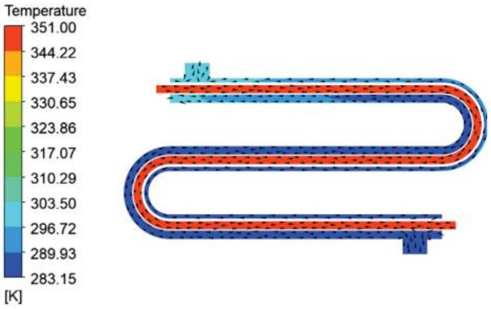

Figure 4: Temperature distribution along the length of the triangle shaped inner pipe.

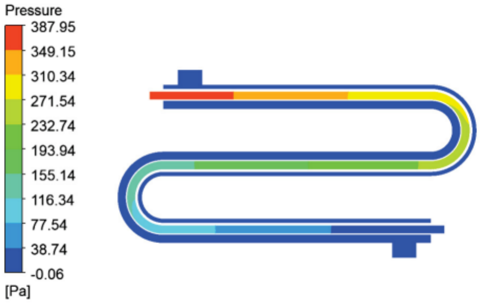

Figure 5: Pressure distribution along the length of the triangle shaped inner pipe.

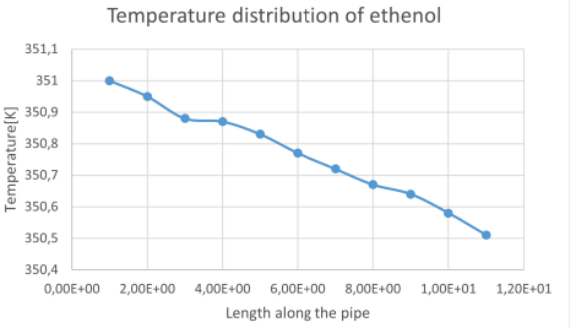

Figure 6: Temperature distribution of ethanol for triangular inner pipe.

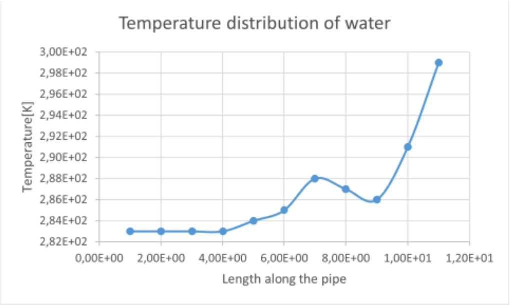

Figure 7: Temperature distribution of water for triangular inner pipe.

Influence of heat transfer in the presence of Hexagonal inner pipe.

A double pipe heat exchanger was designed using a hexagonal inner pipe to study heat transfer throughout its length.

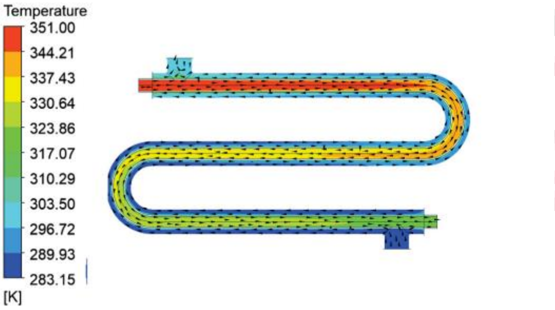

Figure 8: Temperature distribution along the length of the hexagonal inner pipe.

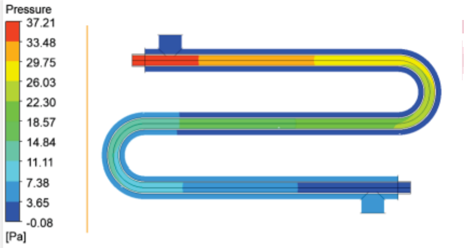

Figure 9: Pressure distribution along the length of the hexagonal inner pipe

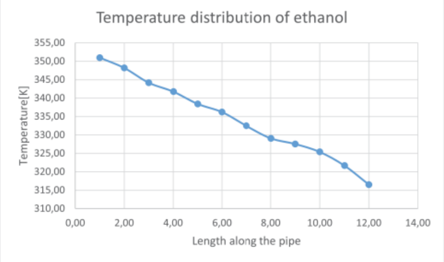

Figure 10: Temperature distribution of ethenol for hexagonal inner pipe

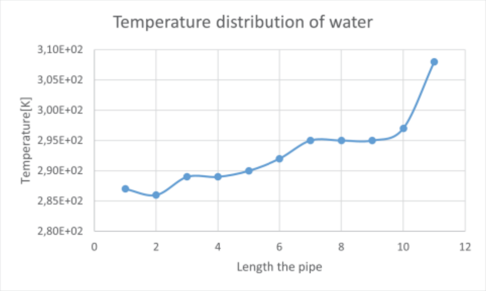

Figure 11: Temperature distribution of water for hexagonal inner pipe

Influence of heat transfer in the presence of octogonal inner pipe.

An octagonal inner pipe was utilized in the design of a double pipe heat exchanger to study heat transfer dynamics along its length.

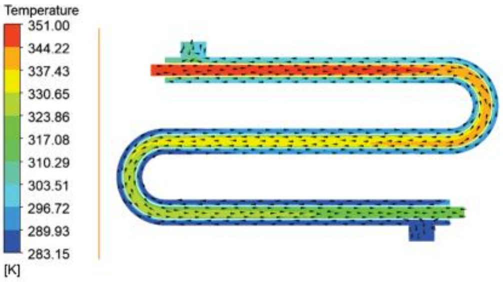

Figure 12: Temperature distribution along the length of the octogonal inner pipe

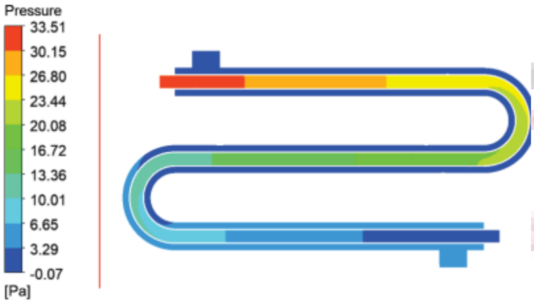

Figure 13: Pressure distribution along the length of the octogonal inner pipe.

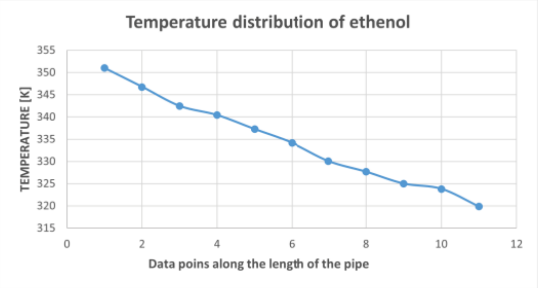

Figure 14: Temperature distribution of ethenol for octagonal shaped inner pipe.

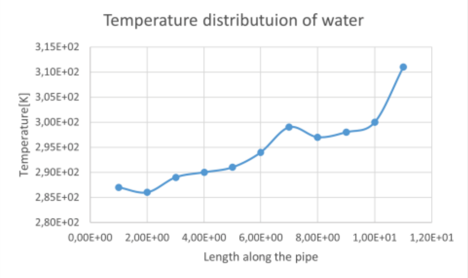

Figure 15: Temperature distribution of water for octogonal shaped inner pipe

Comparison of temperature distribution along the length of the pipe of a double pipe heat exchanger.

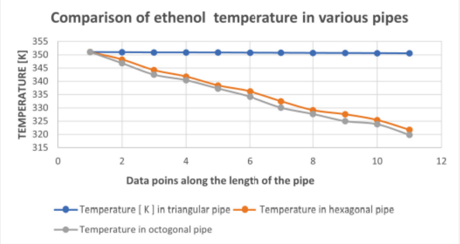

Figure 16: Temperature between various pipe shapes

Influence of heat transfer in the presence of dent to the inner pipe of heat exchanger.

A computational simulation was undertaken on a basic double heat exchanger model to examine heat transfer and thermal hydraulic performance.

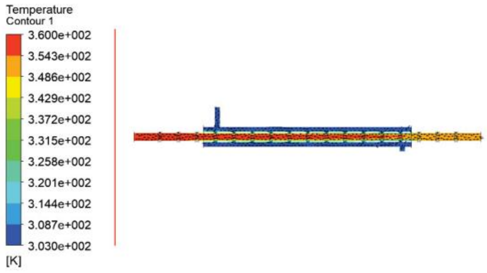

Figure 17: temperature with dent along the length of the pipe.

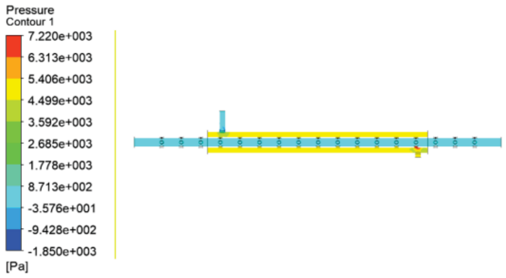

Figure 18: Pressure distribution with dent along the length of the pipe.

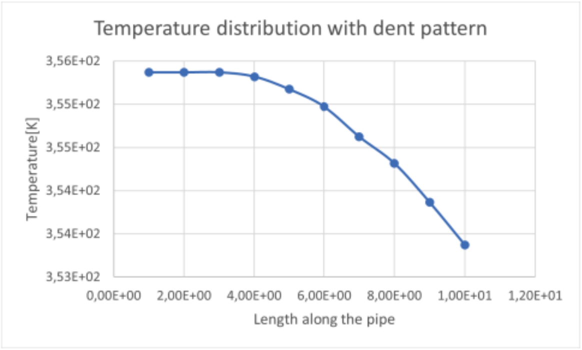

Figure 19: Temperature distribution for dent pattern along the length of the pipe.

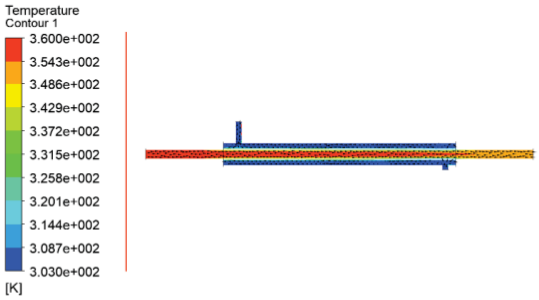

Figure 20: Temperature distribution without dent along the length of the pipe.

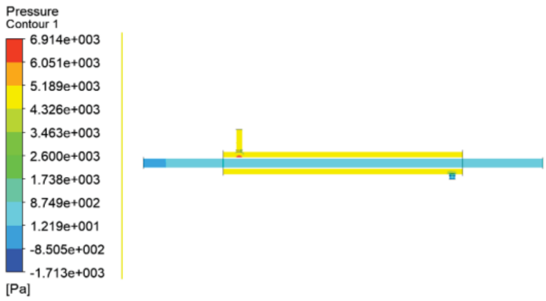

Figure 21: Pressure distribution without dent along the length of the pipe.

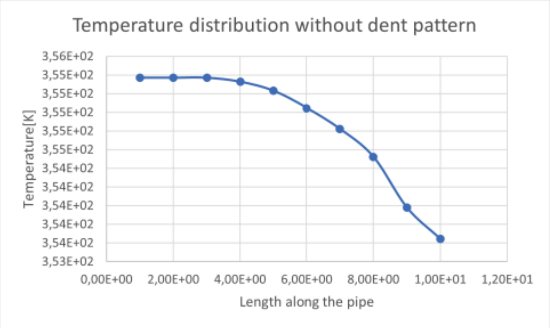

Figure 22: Temperature distribution without dent pattern along the length of the pipe.

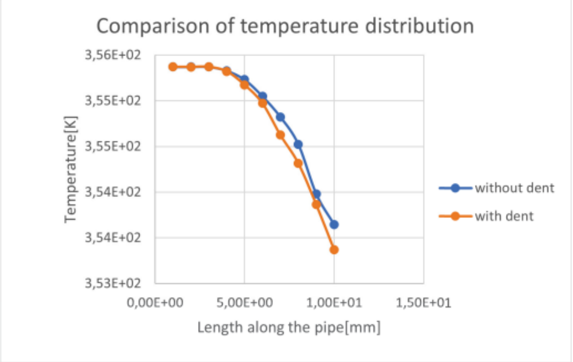

Figure 23: Comparison of temperature distribution between with and without dent.

## CONCLUSION

The study found that octagonal pipes provided the most efficient heat transfer and had minimal pressure distribution. Additionally, a dent pattern on the exterior of the inner pipe was found to enhance heat transfer compared to a regular circular pipe. Several factors influence heat exchanger efficiency, including thermal, mechanical, and manufacturing design. Proper maintenance, including online and offline cleaning methods, is crucial to optimize performance and prolong the exchanger's lifespan. Every work can be improved from time to time with the available technology with the best possible way. The parameters that can be introduced in future work are

- Studying different dimple pattern in analyzing heat transfer.
- Analyzing the flow of various mediums like liquid, semi- liquid and gases.
- Optimization of complex design with respect to particular industrial applications.

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