Influence of Heat Transfer under Different Geometrical Design of Inner Pipe of Heat Exchanger

Md Siraj Anwar[1], Dr Sohail Bux[2]
[1]*MTech Scholar*, [2]*Professor*
[1]*Department of Mechanical Engineering, Agnos College of Technology, Bhopal, India*
[2]*Department of Mechanical Engineering, Agnos College of Technology, Bhopal, India*
sirajanwer1997@gmail.com[1] buxsohail@gmail.com[2]

* Corresponding Author: Md Siraj Anwar

Abstract: *This study delves into the effects of different tube geometries on heat transfer efficiencies within a double pipe heat exchanger. Specifically, triangular, hexagonal, and octagonal pipe shapes were evaluated. Among the shapes studied, the octagonal pipes emerged as the most efficient in terms of heat transfer and showcased favorable pressure distribution characteristics. An external dent pattern on the inner pipe further augmented the heat transfer efficiency, surpassing that of traditional circular pipes. The efficiency of heat exchangers is contingent upon a confluence of factors such as thermal properties, mechanical design, and manufacturing techniques. The research also underscores the importance of diligent maintenance, emphasizing both online and offline cleaning methodologies, to ensure optimum functionality and longevity of the heat exchanger.*

Keywords: *Heat Exchanger, Computational thermal Fluid Dynamics, direct winding heat exchangers, Temperature distribution.*

1. INTRODUCTION

Industrial heat exchangers are specialized equipment designed to facilitate the transfer of thermal energy between different mediums. These devices serve the dual purpose of either heating or cooling the involved elements. In industrial settings, cooling holds particular significance as it plays a crucial role in preventing equipment overheating. There exists a diverse array of heat exchanger types, each characterized by its unique advantages and limitations. Consequently, heat exchangers find wide-ranging applications across various industrial sectors. They are integral components in both cooling and heating systems, serving as essential elements in air conditioning setups and heating infrastructure. In essence, numerous industrial processes demand precise temperature control to function optimally. Therefore, meticulous attention must be devoted to sustaining these processes at their ideal operating temperatures. Within industrial facilities, the indispensability of heat exchangers becomes apparent, as they are instrumental in regulating the temperature of machinery, chemicals, water, gases, and other substances, ensuring safe and efficient operation. Furthermore, heat exchangers also contribute to energy efficiency by capturing excess heat or steam generated as byproducts during operations. This surplus thermal energy can then be repurposed elsewhere, enhancing overall operational efficiency..

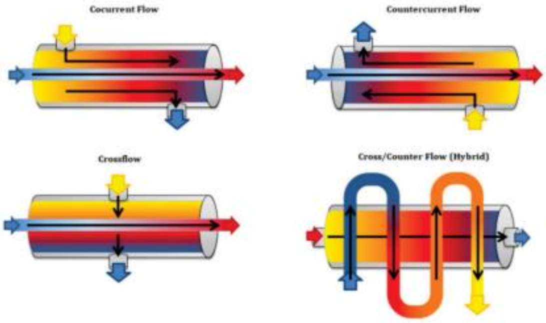

Figure 1: Heat exchanger flow configuration

2. LITERATURE REVIEW

Richard et al. [1] employed Computational Thermal Fluid Dynamics (CtFD) to analyze a meander-flow path fin-type heat exchanger intended for LTS coils in the W7-X stellarator and JT-60SA tokamak. Their study involved testing a mock-up and examining both hydraulic characteristics and heat transfer properties. Sterkhov et al. [2] explored a modernization scheme for existing steam-power units, focusing on gas turbine combined cycles (CCGT) and pressurized heat recovery steam generators (PHRSG). In a separate work, Lin et al. [3] proposed an innovative heat load prediction model based on the hybrid spatial-temporal attention Long Short-Term Memory (STALSTM). Plis et al. [4] developed a model grounded in mass and energy balance equations, as well as empirical relationships describing heat transfer and pressure drop in working fluid within a heat exchanger. Sauciuc et al. [5] delved into the use of phase change systems, such as vapor chambers, to reduce heat sink base spreading resistance. Khan et al. [2], [5]–[8] presented a one-dimensional mathematical model for convective-conductive-radiative fins, incorporating Legendre polynomials and artificial neural networks (ANNs). Their experimental data demonstrated the effectiveness of this design approach compared to contemporary techniques. Sixel et al. [9] introduced a novel application of three-dimensional printed direct winding heat exchangers (3-D-DWHX) to enhance thermal management in high-power-density electric machines. This innovation resulted in increased continuous power ratings and power density for electric machines. Coble et al. [10] conducted calorimetric analysis across the intermediate heat exchanger, enabling real-time inference of the primary flow rate. Liu et al. [11] concentrated on the cryogenic box's structural design, encompassing the vacuum system, refrigerator selection, heat exchanger design, and material choice. Lastly, Gai et al. [12]–[15] explored an oil-based shaft cooling system for a high-speed automotive traction motor. However, they noted that as rotational velocity reached 30,000 r/min, the influence of high rotational speeds on heat exchange diminished due to flow saturation[16].

3. PROPOSED METHODOLOGY

Numerical Methods in Heat Conduction

While we can easily address straightforward heat conduction scenarios involving simple geometries and boundary conditions through analytical methods, practical real-world applications often involve intricate geometries, complex boundary conditions, or variable properties. These complexities make it challenging to obtain analytical solutions. In such cases, we turn to numerical methods and employ computers to obtain accurate approximate solutions. Analytical approaches entail solving the governing differential equation alongside the specified boundary conditions, yielding a mathematical function representing temperature at every point within the medium. Conversely, numerical methods involve replacing the differential equations with a system of n algebraic equations for the unknown temperatures at n selected points within the medium. Solving this system provides temperature values at these 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 $g^{\cdot}_0$

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

$$\frac{dT(0)}{dt}=0andTr_0=T_1 \qquad (2)$$

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

Framework

Utilizing mathematical models for numerical solutions often provides a more accurate representation of real-world engineering problems compared to analytical methods alone.

Flexibility

In the context of engineering challenges, extensive parameter analysis is frequently needed to better comprehend the impact of various variables, aiming for optimal solutions.

Modelling

Geometry in Finite Element Analysis

The study of heat transfer was conducted under specific conditions: a flow rate of 0.1 kg/sec, a turbulent intensity of 5%, and a turbulent viscosity ratio of 10.

Geometric Specifications

For the double-pipe heat exchanger, specific geometric attributes were employed during its construction.

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

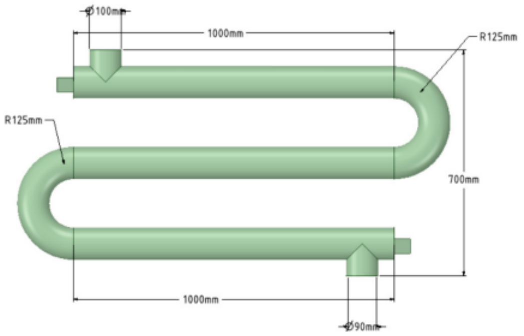

Figure 2: Schematic Illustration of Dimensions Derived from Computational Modelling

The model is constructed based on the preceding geometric parameters specific to dent features.

Table 2: Geometric Characteristics Utilized in the Computational 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

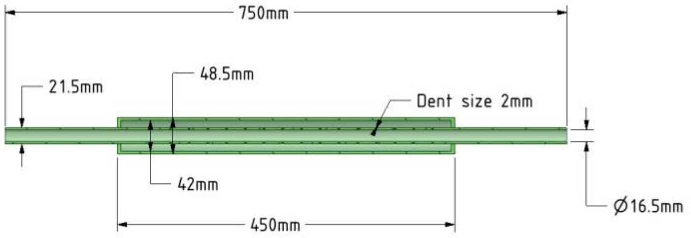

Figure 3: Diagramic representation of dimension from dent model

Material Properties

The numerical model is developed using copper as the base material. The following table details the specific material attributes of copper.

Table 3: Material Characteristics for the Copper-Based Numerical Model.

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 Attributes for the Brass-Composed Numerical Model

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 Specifications for the Ethanol-Based Numerical Model.

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

4. RESULTS

Impact of Heat Transfer with Triangular Inner Pipe

The research involves an investigation into heat transfer across a dual-pipe heat exchanger fitted with an inner pipe of triangular cross-section.

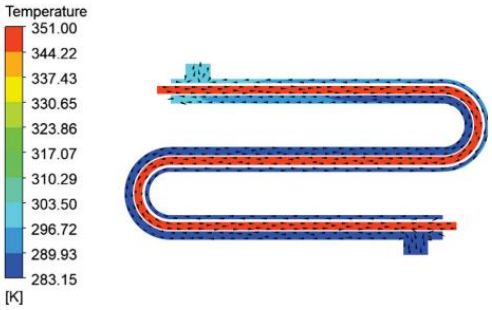

Figure 4: Spatial Temperature Variations in Triangular Inner Pipe

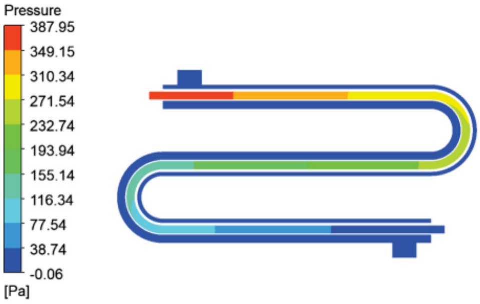

Figure 5: Spatial Pressure Variations in Triangular Inner Pipe

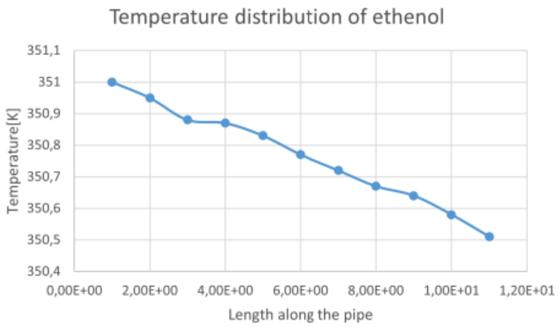

Figure 6: Ethanol Temperature Profile in Triangular Inner Pipe.

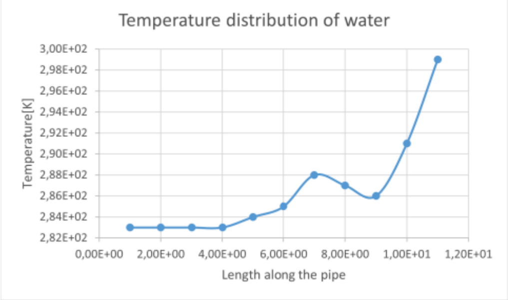

Figure 7: Water Temperature Profile in Triangular Inner Pipe.

Heat Transfer Characteristics with Hexagonal Inner Pipe

For this aspect of the study, a hexagonally-shaped inner pipe was incorporated into the dual-pipe heat exchanger to examine heat transfer properties.

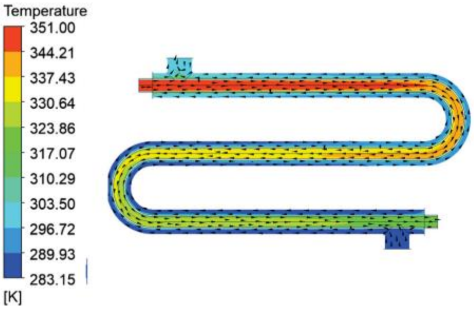

Figure 8: Longitudinal Temperature Variation in Hexagonal Inner Pipe

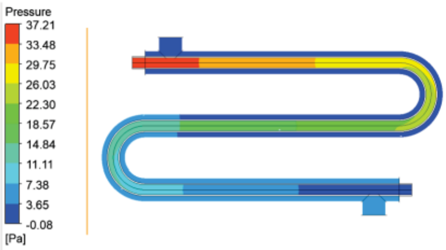

Figure 9: Longitudinal Pressure Variation in Hexagonal Inner Pipe

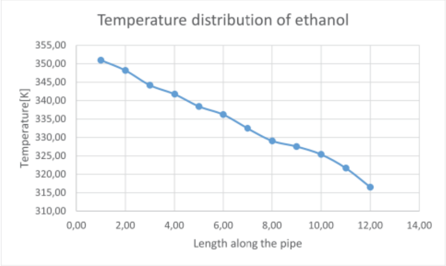

Figure 10: Ethanol Temperature Distribution in Hexagonal Inner Pipe.

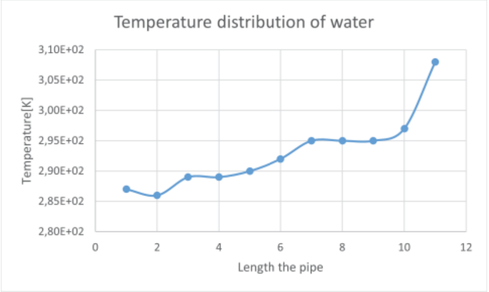

Figure 11: Temperature distribution of water for hexagonal inner pipe

Heat Transfer Dynamics with Octagonal Inner Pipe

An inner pipe with an octagonal shape was used in the dual-pipe heat exchanger setup to scrutinize heat transfer behavior along its length.

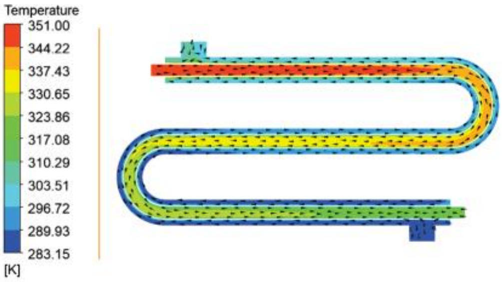

Figure 12: Temperature Gradients in Octagonal Inner Pipe

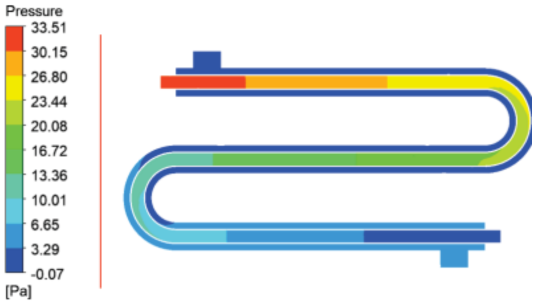

Figure 13: Pressure Gradients in Octagonal Inner Pipe

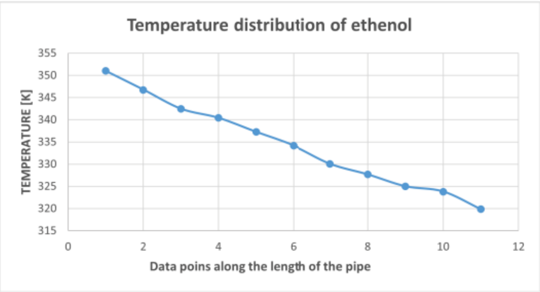

Figure 14: Ethanol Temperature Variations in Octagonal Inner Pipe.

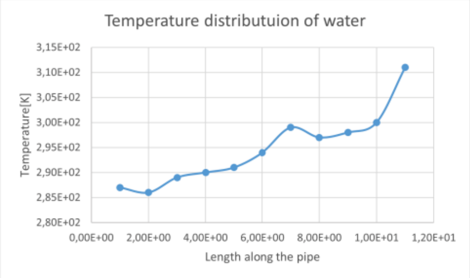

Figure 15: Water Temperature Variations in Octagonal Inner Pipe

Comparative Analysis of Temperature Distribution in Different Pipe Shapes

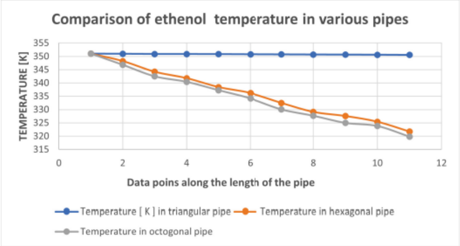

Figure 16: Comparative Temperature Distribution in Various Pipe Configurations.

Heat Transfer Effects Due to Dent in Inner Pipe

Computational simulations were conducted on a standard double-pipe heat exchanger to assess the thermal-hydraulic effects due to the presence of a dent.

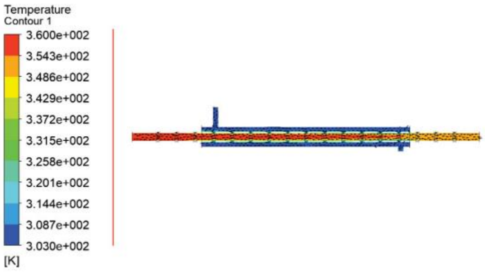

Figure 17: Temperature Profile Along Pipe Length with Dent

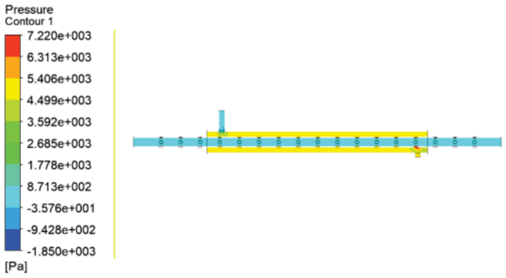

Figure 18: Pressure Profile Along Pipe Length with Dent

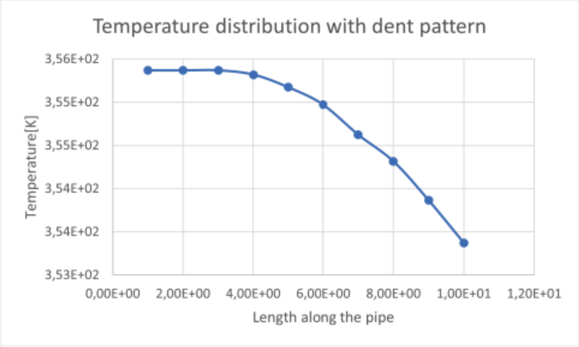

Figure 19: Temperature Distribution Affected by Dent Pattern

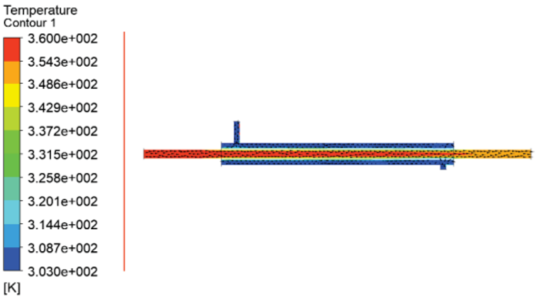

Figure 20: Temperature Profile Without Dent

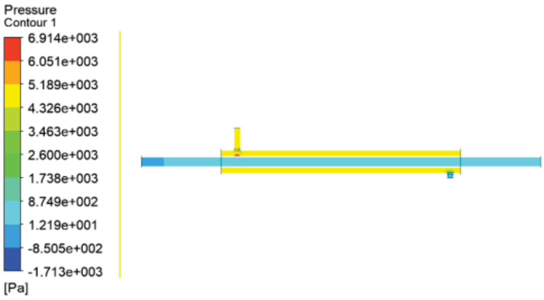

Figure 21: Pressure Profile Without Dent

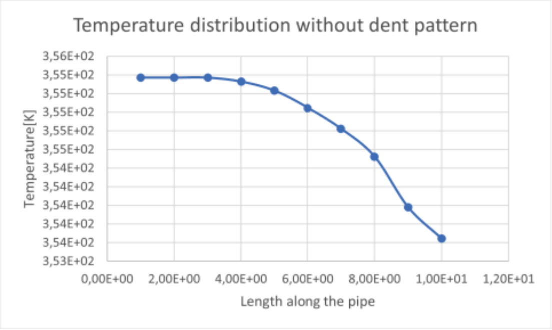

Figure 22: Temperature Distribution Without Presence of Dent Pattern

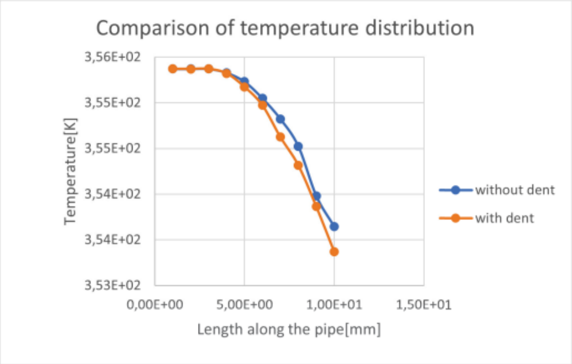

Figure 23: Comparative Analysis of Temperature Distribution with and without Dent.

5. 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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