Impact of Segmental Perforated Baffles on the Thermal Performance of Double Pipe Heat Exchangers: An Experimental Approach

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Abstract: - *This study presents an experimental analysis of the segmental perforated baffles on thermal performance in a double-pipe heat exchanger. An attempt has been made in this respect to optimize the heat transfer and fluid dynamics in the heat exchanger by using a number of baffle configurations, particularly variable shapes and orientations of perforations. A detailed methodology has been adopted based on 3D CAD modeling, ANSYS Workbench integration, and detailed CFD simulations. The results show that the different configurations of baffles vary both the temperature distribution and the fluid velocity. For example, triangular perforation baffles were found to be most efficient at transferring heat; it showed a 12.85% reduction in tube-side temperature and a 9.4% rise in shell-side temperature when compared to other designs. These findings bring out the importance of baffle design in the enhancement of thermal performance while keeping the pressure drop within an acceptable limit for heat exchangers. The result indicates that proper baffle geometry optimization is quite important for enhancing the efficiency of industrial double-pipe heat exchangers.*

Keywords: *Double pipe heat exchanger, segmental perforated baffles, CFD simulation, thermal performance, fluid dynamics, temperature distribution, fluid velocity, baffle configuration.*

I. INTRODUCTION

Heat exchangers (HXs) transfer heat between fluids, which can be in liquid, gas, or solid phases. In industry, they are categorized by configurations, compactness, heat transfer process, flow orders, phase of heat transfer fluids (HTFs), and heat transfer mechanisms [1]. HXs are crucial for removing excess heat from processes and components, such as in aerospace applications where air-to-oil HXs cool lubricating oil in turbofan engines [2]. They are used in various industries for processes like crystallization, distillation, and pasteurization, and include types like cooling towers, air preheaters, and automobile radiators. HXs can be classified by construction into tubular, plate-type, extended surface, and regenerative types, with tubular HXs further divided into double-pipe, shell and tube, spiral tube, and pipe coil [3]

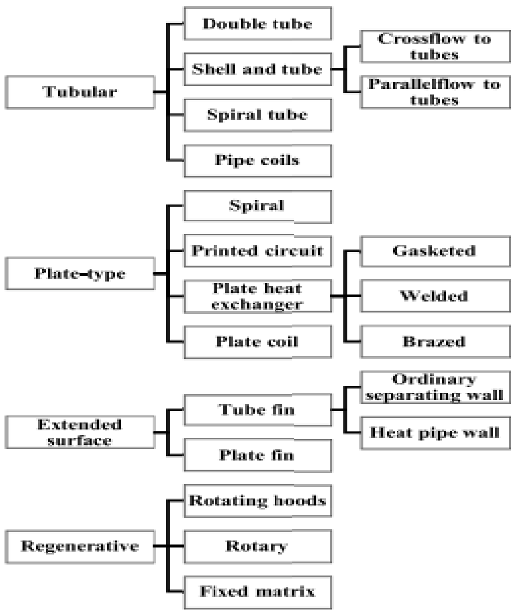

Fig. 1. Classification of heat exchangers according to construction [3]

Double Tube Heat Exchanger (DTHE)

The double tube heat exchanger, otherwise also called a double pipe heat exchanger, means that two concentric pipes are placed within another to form an annular space. Through this annular area, the flow devised passes to offer proper heat exchange between two flowing fluids. One fluid will pass through the inner pipe, whereas the other one circulates in the annular space for effective thermal exchange. These heat exchangers flow with fluids in either counterflow or parallel flow; counterflow arrangements have higher efficiency since the temperature gradient is higher. Because of the simplicity and low cost, double tube heat exchangers are preferred and thus find applications in power plants, chemical processing, and HVAC systems for a multitude of heat transfer needs. Their limitation lies in reduced heat transfer surface area compared to the shell and tube models and possible pressure drops[4]–[11].

It is due to the segmental perforated baffles in the annular space of these exchangers, which improves heat transfer due to induction of turbulence and better fluid mixing, thus improving convective heat transfer coefficient and hence overall thermal performance. This can lead to smaller, more cost-effective heat exchangers while effectively controlling the pressure drops. Such baffles, although useful in especially space-constrained applications, require optimal design for the proper balance between heat transfer efficiency and acceptable pressure losses for industrial processes and HVAC applications [12]–[17].

II. LITERATURE REVIEW

Karimi Shoar et al. (2023) [9] investigated the potential of heating natural gas at city gate gas pressure reduction stations to avoid the formation of hydrates in throttle valves. Their work explored fouling in heat exchangers, which become an integral factor in industrial energy systems. In this simulation of fouling processes, the dynamically changing parameters—including fouling strength and layer thickness—were calculated by C++ coding with user-defined functions. The findings from the study proved that fouling rates increased with an increase in the concentration of fouling species and surface temperature, but decreased with an increase in gas inlet velocity where fluid inlet temperature and concentration of fouling species were low. This model is estimated to run for about 190 days for 70% efficiency in a heat exchanger having a critical fouling layer thickness of 3.5 cm.

Natesan, K., & Karinka, S. (2023) [10] studied that the industrial growth of any country depends on energy source availability and utilization of energy for various applications. The heat exchanger is a heat transfer device which is most widely used in various applications for effective heat transfer between cold and hot fluids. Any improvement in heat transfer results in enhancement in overall performance of the device. Hence various techniques are used to improve the heat transfer. The solid particles which have higher thermal conductivity and can be used to improve the heat transfer between hot and cold fluids. The thermal conductivity of graphene-based nanoparticle is high, and it has low erosion, corrosion, higher stability, etc. Hence graphene-based nanoparticle is chosen in various heat transfer applications. The use of graphene-based nanoparticles increases the heat transfer and hence it can reduce the size of the heat transfer equipment. This study critically reviews various applications of graphene in different types of heat exchangers, electronic devices challenges and opportunities, by highlighting the advantages of using graphene.

Md Atiqur Rahman (2024) [11] aimed to investigate the heat transfer (HT) properties of a tubular heat exchanger (HX) by using innovative baffle plate arrangements. The newly designed baffle plate was circular with triangular openings and adjustable triangular flow deflectors. These deflectors were strategically placed at the inlet of the HX to create a swirling flow downstream. Three baffle plates were installed along the flow direction with different length-to-diameter ratios (pitch ratios) to assess their impact on HT, pressure drop, and thermal enhancement factor. The study compared these results with a smooth channel under varying Reynolds numbers (16,500–29,500). The findings revealed that both the pitch ratio (0.6–1.2) and the inclination angle of the deflectors (30º–50º) significantly affected the HX's performance. Notably, the baffle plate with a deflector inclination angle of 30° and a pitch ratio of 1 showed a remarkable average improvement of 36.5% compared to other angles and ratios.

Eiamsa-ard et al. (2023) [12] carried out an experiment on the influence of DW-PVBs on heat transfer and pressure loss in a channel. Such baffles, for the purpose of stirring enhancement, are designed in such a manner as to produce counter-rotating vortices in the channel, which provides a useful way for improving the heat transfer by. The DW-PVBs of various geometric characteristics were tested: relative baffle blockage ratios, pitch ratios, and attack angles ($\theta = 0°$, 22.5°, 45°, 67.5°, and 90°) in air flow at Reynolds numbers of 6000–24,000. They found that smaller flow attack angles of the baffles ($\theta = 22.5°$) found better heat transfer rates compared to other designs of the flow attack angle, whereas $\theta = 45°$ provided the highest TPF with 13.64–17.26% of reduction in friction factor for solid V-shaped baffles. For the DW-PVBs, the maximum obtained TPF values are up to 1.91 at Re = 6000.

H. O. Sayevand et al. (2023) [13] studied the overall performance of a heat exchanger shell-and-double-concentric-tube with simple and perforated helical baffles is investigated in the shell side of the heat exchanger using ANSYS FLUENT

19.2. A comparison between the shell-side with simple helical baffles of the heat exchanger (SHB-SDCTHEX) and the one with perforated helical baffles (PHB-SDCTHEX) using numerous mass flow rates is carried out. For the perforated helical baffles heat transfer rate Q, thermo-hydraulic performance $Q/\Delta P$ and effectiveness ε are around 26.7%, 55.5% and 26.6% higher than the same parameters for the simple helical baffles of the heat exchanger, respectively. It is also observed that the flow and temperature distribution for the perforated helical baffles are more uniform with higher flow turbulence than the simple helical baffles of the heat exchanger. So, the perforated helical baffles could be a better choice for the designers and manufacturers with respect to the simple helical baffles of the heat exchanger.

III. OBJECTIVES

- To investigate the convective heat transfer and pressure drop in an annulus with perforated SSPBs aligned along the inner heated tube surface, using water as a working fluid by using CFD analysis.
- To develop a proposed model for SSPB with optimised geometrical parameters and compare with existing base experimental results.

IV. METHODOLOGY

The study evaluates the influence of various baffle configurations on fluid dynamics and thermal efficiency in double-tube heat exchangers. It also optimizes the heat transfer mechanism within the DTHE to further enhance its overall performance. The study takes an in-depth look into various designs for baffles, ranging from no baffles to those with unique perforation patterns, to determine those effective in the improvement of heat exchanger efficiency. The methodology is very structured, involving first the development of the exact baffle design. After that, a well-ordered series of cases unfolded. This includes the complete CAD model creation process, integration in ANSYS Workbench for running the CFD analysis, and refinement of the model. The key elements for mesh generation, Fluent solver configuration, and definition of cell-zone conditions are also included. These optimal baffle designs will then be screened based on their interaction with fluid dynamics and heat transfer performance using detailed simulation and analysis.

1. **3D CAD Modelling:** In the initial phase, a highly detailed 3D CAD model of the DTHE is meticulously developed. This model is tailored to incorporate the specific geometry and dimensions required for each distinct baffle configuration under investigation. The accuracy and completeness of this CAD model are paramount to ensure a faithful representation of the physical system.
2. **ANSYS Workbench Integration:** Following the CAD modeling phase, the model is seamlessly integrated into ANSYS Workbench. This integration is pivotal as it harnesses the computational fluid dynamics (CFD) capabilities of ANSYS Workbench for in-depth analysis.
3. **Design Modeler Cleanup:** Within ANSYS Workbench, the Design Modeler tool is employed to undertake a thorough cleaning and refinement of the 3D CAD model. This step is crucial to eliminate any potential artifacts, ensuring the model's accuracy and reliability throughout the simulation process.
4. **Mesh Generation:** Mesh generation is a pivotal aspect of the methodology. It entails creating an appropriate mesh for the DTHE model, with adjustments made to mesh density as necessary to ensure dependable simulation results. An effectively structured mesh is essential for the accurate modeling of fluid flow and heat transfer.
5. **Fluent Solver Setup:** The configuration of the Fluent solver settings is a fundamental step. Researchers meticulously define boundary conditions, turbulence models (such as the k-epsilon model with realizable scale), and material properties for all components involved, including water, PVC, and copper. These settings are imperative for precisely simulating fluid behavior and heat transfer within the DTHE.
6. **Cell-Zone Conditions:** To distinguish between solid domains (representing PVC and copper baffles) and the fluid domain (representing water-liquid), specific cell-zone conditions are defined. This differentiation is critical for accurately capturing the interaction between the baffles and the fluid.
7. **Baffle Configurations:** The heart of the study lies in introducing particular baffle configurations for each case. These configurations span the spectrum from scenarios with no baffles to those featuring intricate perforation patterns, including circular, square, elliptical, triangular, and rhombus shapes. Additionally, variations in hole

alignment are explored. These diverse configurations permit a comprehensive examination of their effects on heat transfer and fluid dynamics.

8. **Inlet and Outlet Boundary Conditions:** To ensure a realistic simulation, inlet and outlet boundary conditions are meticulously set for both the inner tube (made of copper) and the outer shell (constructed from PVC). These conditions include parameters such as mass flow rates, temperatures, and pressure outlets, crucial for replicating real-world operating conditions.

9. **Simulation Execution:** Once all parameters and conditions are configured, the simulation is initiated and executed within the Fluent solver. This phase allows for the calculation of temperature and velocity profiles within the DTHE for each baffle configuration.

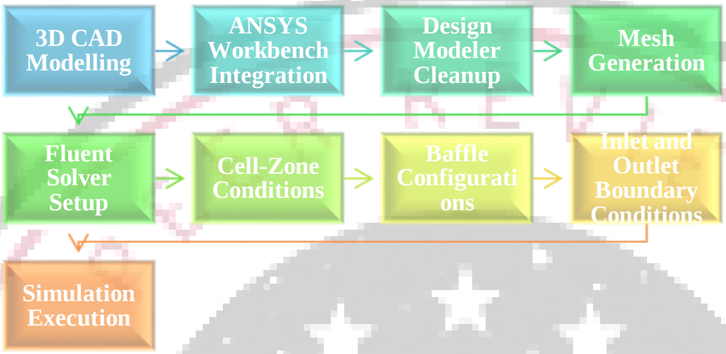

Figure 4.1 Flow Chart of Adopted Methodology

Cases Considered in this Study

The study investigation involves a meticulously structured exploration of various baffle configurations within the context of the double-tube heat exchanger (DTHE). These distinct configurations have been thoughtfully selected to comprehensively assess their impact on the DTHE's performance. Here is an elaboration of each specific case:

- Case 1: **No Baffles -** In this scenario, the DTHE operates without any baffles. This example provides a foundation for comprehending the heat exchanger's inherent fluid dynamics and heat transfer in the absence of any disruptive factors.
- Case 2: **Baffles with No Holes -** Baffles are introduced into the DTHE, but they do not feature any perforations or holes. This configuration tests the effect of baffles themselves on heat transfer and fluid flow, without the additional complexity of holes.
- Case 3: **Baffles with Circular Holes -** The baffles in this case are equipped with circular holes. Circular perforations are known for their uniformity, and this configuration investigates their influence on heat exchanger performance.
- Case 4: **Baffles with Square Holes -** In this scenario, the baffles are designed with square holes. Square perforations introduce a different geometric element, and their impact on heat transfer and fluid flow is a key focus of this case.
- Case 5: **Baffles with Elliptical Holes (Major Axis Horizontally Aligned) -** Baffles featuring elliptical holes with horizontally aligned major axes are examined in this case. To assess the effect of elliptical perforations on heat exchanger performance, it is crucial to take their orientation into account. These perforations produce asymmetry.
- Case 6: **Baffles with Triangular Holes -** Triangular holes are incorporated into the baffles in this case. The unique shape of triangular perforations brings a different set of challenges and opportunities, making this configuration noteworthy for analysis.
- Case 7: **Baffles with Rhombus Holes -** The baffles in this case are equipped with rhombus-shaped holes. Rhombus perforations introduce yet another geometric variation, and their impact on heat transfer and fluid dynamics is a focal point of investigation.

- Case 8: **Baffles with Elliptical Holes (Major Axis Vertically Aligned) -** Similar to Case 5, this scenario involves baffles with elliptical holes, but with their major axes aligned vertically. The orientation of the elliptical perforations in this case introduces a different dynamic into the study, exploring the influence of orientation on heat exchanger performance.

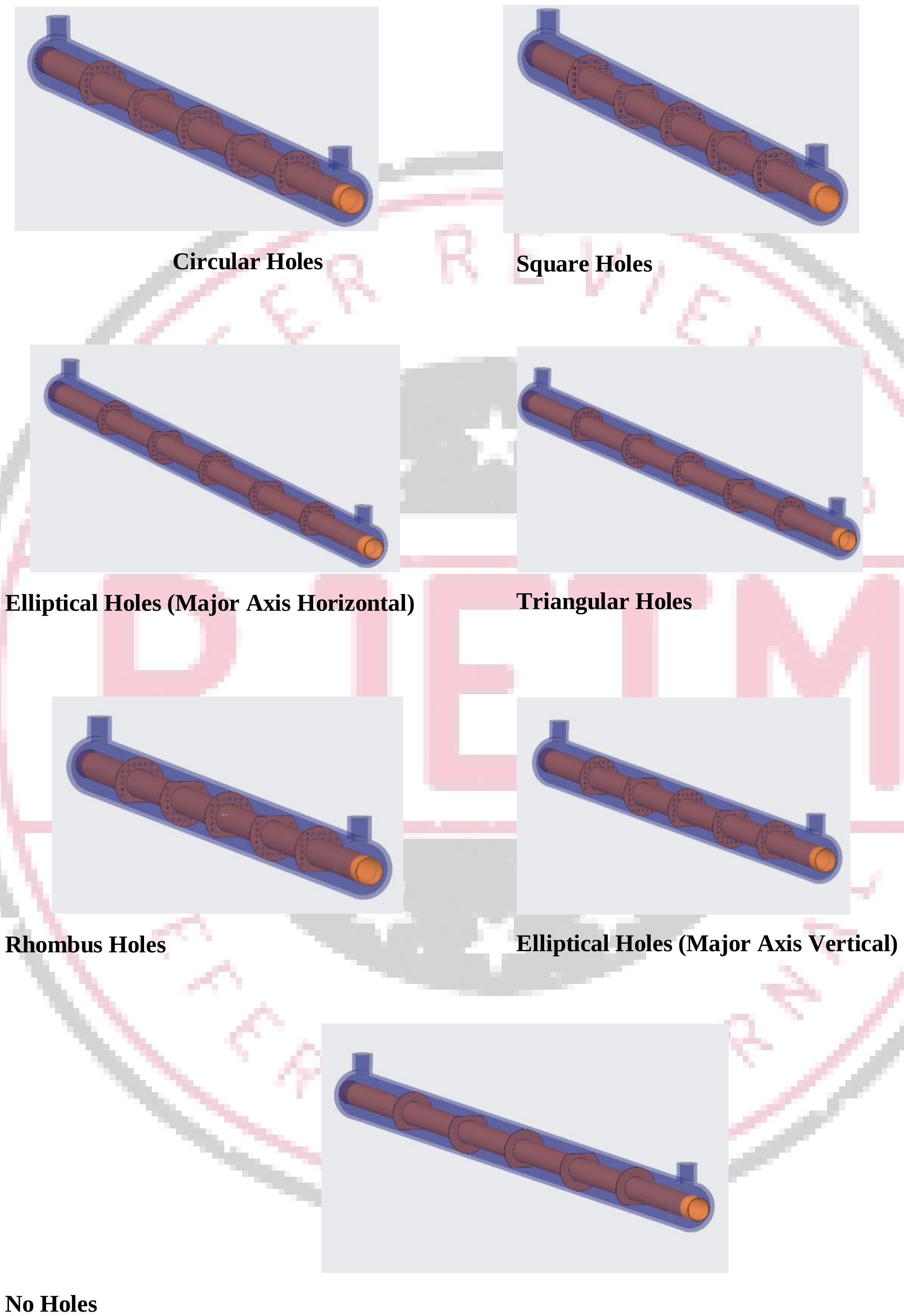

Figure 4.2 Specific CASES Considered in this Study

In the first stage of this study, the performance of the baffled-less double-tube heat exchanger (DTHE) was considered. For this, a meticulous 3D CAD model representing the correct geometry and dimensions of a baffle-less DTHE was created. The 3D model was then imported into ANSYS Workbench and prepared for further CFD simulations. Perfecting the CAD model to make it free of errors and anomalies was done using the Design Modeler tool. Afterwards, mesh creation was done by designing a mesh structure that is appropriate in modeling heat transfer and fluid flow within

DTHE. This setup would give a foundation to the analysis of the effects of the lack of baffles on the performance of the heat exchanger by providing accurate and precise simulation results.

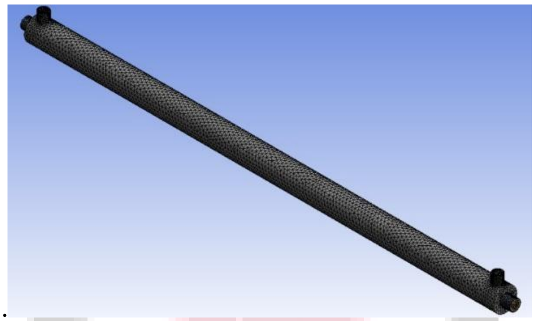

Figure 4.3 Meshing of DTHE

In the simulation setup for the double-tube heat exchanger (DTHE), several key steps and parameters were carefully configured. Constant pressure-based boundary conditions were applied, and gravity effects were included. The energy equation was activated to model heat transfer. The k-epsilon turbulence model with the realizable scale model and standard wall functions was used to capture turbulent flow accurately. Material properties for water, PVC, and copper were sourced from the Fluent material database. The solid domain was set as PVC for the outer shell and copper for the inner tube and baffles, while water was used for the fluid domain. The inner tube had an inlet mass flow rate of 0.1343 kg/s at 50°C, with a pressure outlet at the exit. The outer shell had a mass flow rate of 0.2 kg/s and a pressure outlet. These configurations ensured the simulation accurately represented real-world conditions, allowing for a thorough analysis of heat transfer and fluid flow performance with different baffle configurations.

Table 4.1: Boundary conditions for DTHE

Component	**Condition**	**Details**
Inner Tube (Copper)	Inlet	MFR: 0.1343 kg/s Temperature: 50°C
	Outlet	Pressure Outlet
Outer Shell (PVC)	Inlet (opposite to shell)	MFR: 0.2 kg/s
	Outlet	Pressure Outlet

Figure 4.4 Fluent Solver Boundary Conditions

These boundary conditions outline the specific settings applied to the inner tube (made of copper) and the outer shell (constructed from PVC) within the double-tube heat exchanger (DTHE) simulation.

V. RESULTS AND DISCUSSIONS

A comprehensive analysis was conducted to evaluate the thermal and fluid dynamics behaviour within the DTHE under the specified conditions, with the findings detailed in the results section. Visual representations, including images and visualizations, were presented to illustrate the temperature distribution throughout the DTHE. These visualizations allowed for the clear observation and documentation of temperature variations that occurred as a direct result of the absence of baffles within the heat exchanger. Furthermore, the velocity profile within the fluid domain was also extensively examined, with visual representations showcasing the distribution of fluid velocity. This analysis included a detailed assessment of changes in fluid flow patterns induced by the absence of baffles. To provide a more comprehensive understanding of the results obtained, specific temperature and velocity values were recorded at both the inlet and outlet points for both the tube side and the shell side of the DTHE.

5.1 Case 1: No Baffles

In this case, the impact of "No Baffles" on a double-tube heat exchanger (DTHE). It presented visualizations of temperature distribution and documented temperature variations due to the absence of baffles. Additionally, visual representations of fluid velocity distribution were provided, along with an analysis of how fluid flow patterns changed without baffles. These results offer valuable insights into the DTHE's thermal and fluid behavior under this specific condition.

Table 5.1: Temperature and Velocity for Tube and Shell Sides with No Baffles

No baffles		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	48.44
Shell side	15.00	18.54
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.37
Shell side	0.90	1.06

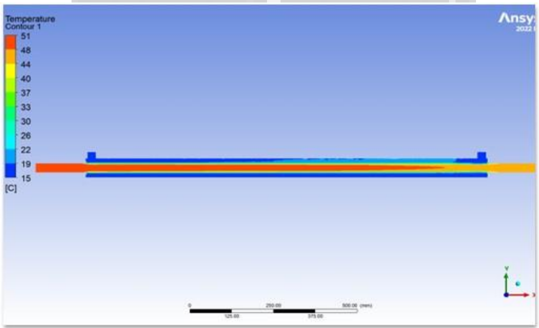

Figure 5.1 Temperature distributions within the DTHE

The temperature measurements for the "No Baffles" condition in the double-tube heat exchanger (DTHE) were as follows: On the tube side, the inlet temperature was 50.00°C, and the outlet temperature was 48.44°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 18.54°C.

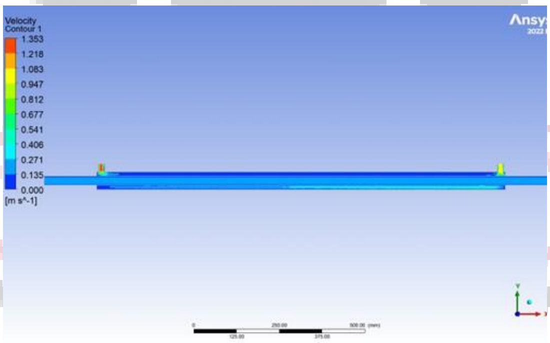

Figure 5.2 Velocity distributions within the DTHE

The velocity measurements obtained during the analysis of the "No Baffles" condition in the double-tube heat exchanger (DTHE) are as follows:

For the tube side of the DTHE, the velocity was measured at 0.26 m/s at the inlet and increased to 0.37 m/s at the outlet. The velocity on the external side of the DTHE was recorded at 0.90 m/s at the inlet and increased to 1.06 m/s at the outlet.

5.2 Case 2: Baffles with No Holes

The investigation revolved around comprehending how solid baffles, devoid of any openings or apertures, influence the heat exchanger's overall functionality. Baffles, typically designed to alter fluid flow and enhance heat transfer within the

DTHE, were examined in their purest form, i.e., without any holes or openings that might introduce additional complexities. The study aimed to elucidate how these solid baffles, when unperforated, affect parameters such as temperature distribution and fluid velocity profiles.

Table 5.2: Temperature and Velocity for Tube and Shell Sides with No hole Baffles

Baffles with No hole		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	44.75
Shell side	15.00	24.14
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.37
Shell side	0.90	0.96

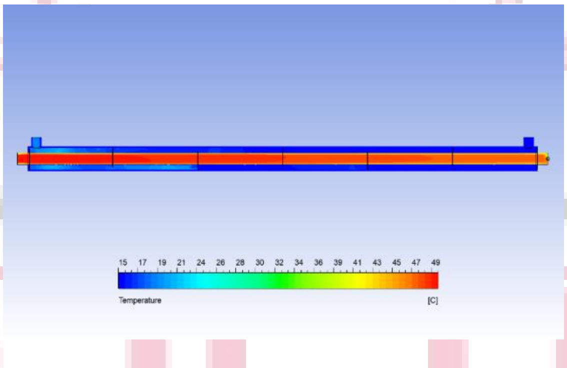

Figure 5.3 Temperature distributions within the DTHE with Baffle without holes

The temperature readings recorded during the analysis of the "Baffles with No Holes" condition within the double-tube heat exchanger (DTHE) are as follows:

Within the DTHE, the temperature at the inlet was 50.00°C, and it decreased to 44.75°C at the outlet. In contrast, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 24.14°C.

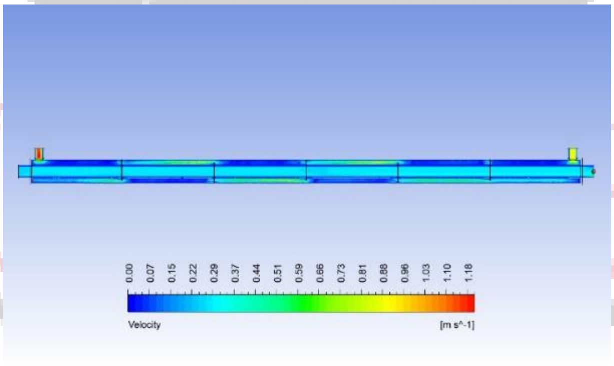

Figure 5.4 Velocity distributions within the DTHE with Baffle without holes

The velocity measurements obtained during the analysis of the "Baffles with No Holes" condition in the double-tube heat exchanger (DTHE) are as follows:

In the double-pipe heat exchanger, the tube side velocity at the inlet was 0.26 m/s and rose to 0.37 m/s at the outlet. On the shell side, the velocity started at 0.90 m/s and experienced a slight increase to 0.96 m/s by the outlet.

5.3 Case 3: Baffles with Circular Holes

The essence of this case is to thoroughly investigate how the incorporation of circular perforations within baffles affects the overall performance of a double-tube heat exchanger (DTHE). In this context, the primary objective was to investigate the impact of circular holes introduced in the baffles. These openings are strategically designed to alter fluid flow patterns and improve heat transfer processes within the DTHE. By studying the impact of circular perforations, the study aimed to gain comprehensive insights into how these particular modifications influence critical parameters such as temperature distribution and fluid velocity profiles, within the DTHE.

Table 5.3: Temperature and Velocity with Circular Hole Baffles

Circular holes		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	44.57
Shell side	15.00	18.90
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	1.12

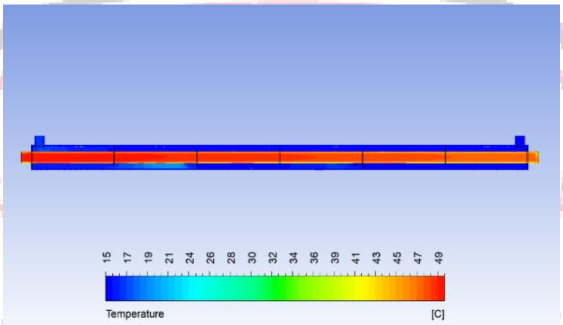

Figure 5.5 Temperature distributions within the DTHE with Baffle with circular holes.

The temperature readings recorded during the analysis of the "Baffles with Circular Holes" condition within the double-tube heat exchanger (DTHE) are as follows:

Within the internal tube of the DTHE, the temperature at the inlet was recorded at 50.00°C, while at the outlet; it decreased slightly to 44.57°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 18.90°C.

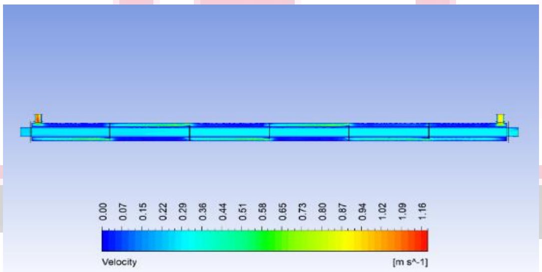

Figure 5.6 Velocity distributions within the DTHE with Baffle with circular holes

The velocity measurements obtained during the analysis of the "Baffles with Circular Holes" condition in the double-tube heat exchanger (DTHE) are as follows:

Inside the double-pipe heat exchanger, the internal flow velocity started at 0.26 m/s at the inlet and increased to 0.38 m/s by the outlet. On the external shell side, the inlet velocity was 0.90 m/s, which grew to 1.12 m/s at the outlet.

5.4 Case 4: Baffles with Square Holes

In this case, the primary focus lies in assessing how square holes strategically introduced in the baffles influence the heat exchanger's functionality. Square perforations are incorporated to alter fluid flow patterns and improve heat transfer efficiency within the DTHE. Therefore, this study aimed to provide a comprehensive understanding of how these specific square openings impact critical parameters such as temperature distribution and fluid velocity profiles within the heat exchanger.

Table 5.4: Temperature and Velocity with Square Hole Baffles

Square holes		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	44.84
Shell side	15.00	16.93
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	1.01

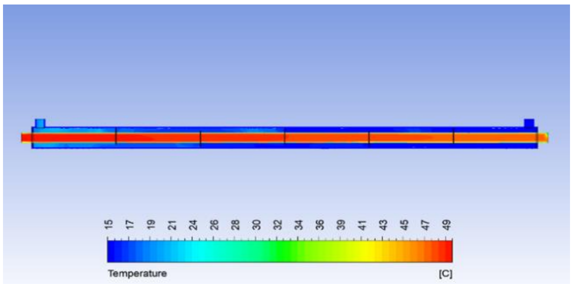

Figure 5.7 Temperature distributions within the DTHE with Baffle with square holes

The temperature readings obtained during the analysis of the "Baffles with Square Holes" condition within the double-tube heat exchanger (DTHE) are as follows:

Within the DTHE, the temperature on the tube side was recorded at 50.00°C at the inlet, and slightly decreased to 44.84°C at the outlet. In contrast, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 16.93°C.

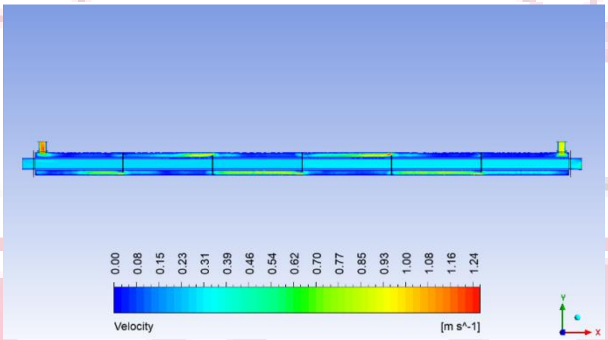

Figure 5.8 Velocity distributions within the DTHE with Baffle with square holes

The velocity measurements obtained during the analysis of the "Baffles with Square Holes" condition in the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the velocity at the inlet was recorded at 0.26 m/s, while at the outlet, it increased to 0.38 m/s. For the shell side of the double-pipe heat exchanger, the velocity rose from 0.90 m/s at the inlet to 1.01 m/s at the outlet.

5.5 Case 5: Baffles with Elliptical Holes (Major Axis Horizontally Aligned)

The primary objective of this case is to assess how these elliptical holes, designed with a specific alignment, influence the heat exchanger's functionality. Elliptical perforations are strategically incorporated to alter fluid flow patterns and improve heat transfer processes within the DTHE. Thus, this study aims to provide a comprehensive understanding of how these elliptical openings, aligned in a horizontal fashion, impact critical parameters such as temperature distribution and fluid velocity profiles within the heat exchanger.

Table 5.5: Temperature and Velocity with Elliptical Holes Horizontally Aligned Baffles

Elliptical holes horizontally aligned		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	43.70
Shell side	15.00	19.61
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	1.08

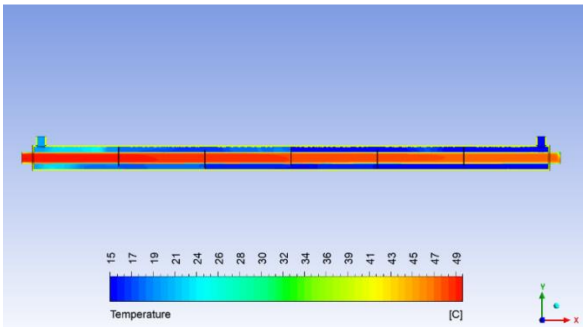

Figure 5.9 Temperature distributions within the DTHE with Baffle with Elliptical Holes

The temperature readings obtained during the analysis of the "Baffles with Elliptical Holes (Major Axis Horizontally Aligned)" condition within the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the temperature at the inlet was recorded at 50.00°C, while at the outlet; it measured slightly lower at 43.70°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 19.61°C.

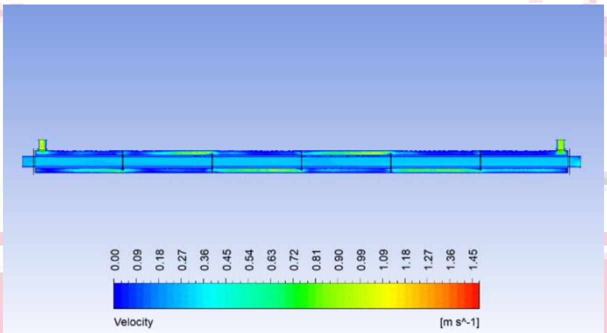

Figure 5.10 Velocity distributions within the DTHE with Baffle with Elliptical Holes

The velocity measurements obtained during the analysis of the "Baffles with Elliptical Holes (Major Axis Horizontally Aligned)" condition in the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the velocity at the inlet was recorded at 0.26 m/s, while at the outlet, it increased to 0.38 m/s. For the shell side of the double-pipe heat exchanger, the velocity increased from 0.90 m/s at the inlet to 1.08 m/s at the outlet.

5.6 Case 6: Baffles with Triangular Holes

This case study aims to examine in detail how incorporating triangular holes into baffles impacts the overall performance of DTHE. The main goal is to determine how the heat exchanger's performance is affected by these carefully placed triangle holes in the baffles. Triangular perforations are introduced to modify fluid flow patterns and improve heat transfer processes within the DTHE.

Table 5.6: Temperature and Velocity with Triangular holes

Triangular holes		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	43.57
Shell side	15.00	20.40
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	1.03

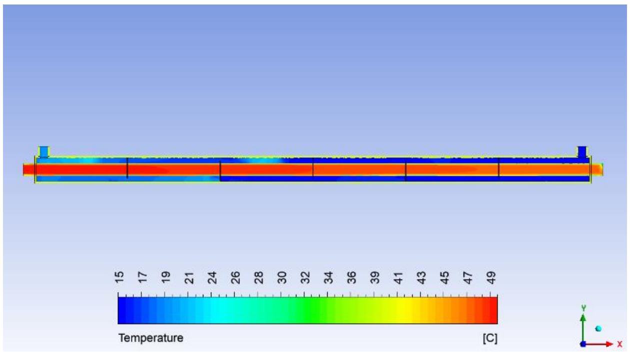

Figure 5.11 Temperature distributions within the DTHE with Baffle with Triangular Holes

The temperature measurements obtained during the analysis of the "Baffles with Triangular Holes" condition within the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the temperature at the inlet was recorded at 50.00°C, while at the outlet, it measured slightly lower at 43.57°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 20.40°C.

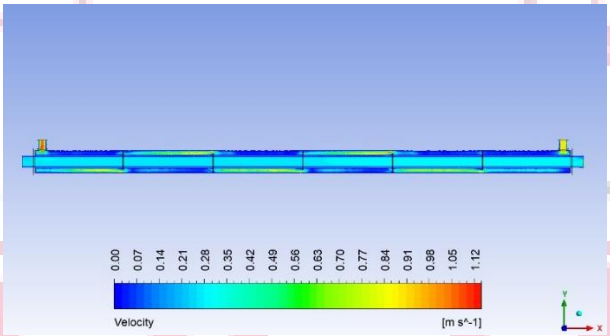

Figure 5.12 Velocity distributions within the DTHE with Baffle with Triangular Holes

The velocity measurements obtained during the analysis of the "Baffles with Triangular Holes" condition in the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the velocity at the inlet was recorded at 0.26 m/s, while at the outlet, it increased to 0.38 m/s. For the shell side of the double-pipe heat exchanger, the inlet velocity was 0.90 m/s, which increased to 1.03 m/s at the outlet.

5.7 Case 7: Baffles with Rhombus Holes

The goal of this case study was to evaluate in detail how baffles with rhombus-shaped holes affected a double-tube heat exchanger's (DTHE) overall performance. The main goal is to find out how the heat exchanger's functioning properties are impacted by these carefully placed, rhombus-shaped holes in the baffles. The addition of rhombus-shaped perforations aims to alter fluid flow patterns and boost heat transfer processes within the DTHE.

Table 5.7: Temperature and Velocity with Rhombus Holes

Rhombus holes		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	44.18
Shell side	15.00	19.90
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	1.02

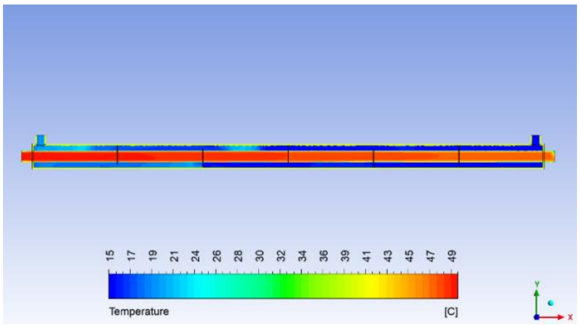

Figure 5.13 Temperature distributions within the DTHE with Baffle with Rhombus Holes

The temperature measurements obtained during the analysis of the "Baffles with Rhombus Holes" condition within the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the temperature at the inlet was recorded at 50.00°C, while at the outlet, it measured slightly lower at 44.18°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 19.90°C.

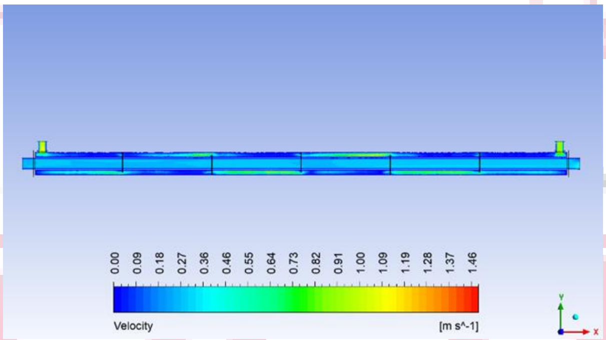

Figure 5.14 Velocity distributions within the DTHE with Baffle with Rhombus Holes

The velocity measurements obtained during the analysis of the "Baffles with Rhombus Holes" condition in the double-tube heat exchanger (DTHE) are as follows: On the tube side of the DTHE, the velocity at the inlet was recorded at 0.26 m/s, and at the outlet, it increased to 0.38 m/s. On the shell side of the DTHE, the velocity at the inlet was 0.90 meter per second, and at the outlet, it increased to 1.02 meter per second.

5.8 Case 8: Baffles with Elliptical Holes (Major Axis Vertically Aligned)

This instance is on evaluating in detail how elliptical-shaped perforations integrated into baffles—where the ellipses' primary axis is vertically aligned—affects a double-tube heat exchanger's (DTHE) overall performance. The main goal is to investigate the effects on the heat exchanger's efficiency and operating characteristics of adding these vertically aligned elliptical holes to the baffles. The addition of elliptical perforations is designed to strategically modify fluid flow patterns and improve heat transfer processes within the DTHE.

Table 5.8: Temperature and Velocity with Elliptical Holes Vertically Aligned

Elliptical holes vertically aligned		
Temperature (°C)	**At Inlet**	**At Outlet**
Tube side	50.00	44.38
Shell side	15.00	19.50
Velocity (m/s)	**At Inlet**	**At Outlet**
Tube side	0.26	0.38
Shell side	0.90	0.95

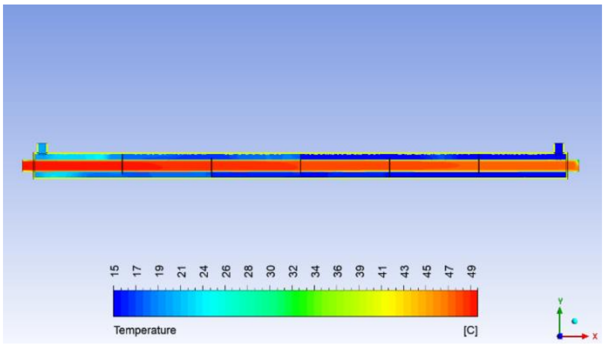

Figure 5.15 Temperature distributions within the DTHE with Baffle with with Elliptical Holes (Major Axis Vertically Aligned)

The temperature measurements obtained during the analysis of the "Elliptical Perforations in Baffles with Major Axis Vertically Aligned" condition within the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the temperature at the inlet was recorded at 50.00°C, while at the outlet, it measured 44.38°C. Conversely, on the shell side of the DTHE, the temperature at the inlet was notably lower at 15.00°C, and at the outlet, it increased to 19.50°C.

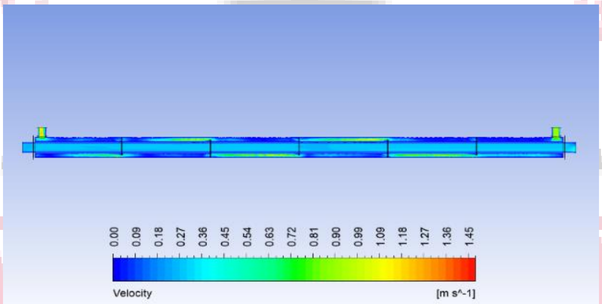

Figure 5.16 Velocity distributions within the DTHE with Baffle with with Elliptical Holes (Major Axis Vertically Aligned)

The velocity measurements obtained during the analysis of the "Elliptical Perforations in Baffles with Major Axis Vertically Aligned" condition within the double-tube heat exchanger (DTHE) are as follows:

On the tube side of the DTHE, the velocity at the inlet was recorded at 0.26 m/s, and at the outlet, it increased to 0.38 m/s.

On the shell side of the DTHE, the velocity at the inlet was 0.90 meter per second, and at the outlet, it slightly decreased to 0.95 meter per second.

5.9 Comparative Results

5.9.1 Comparative Results for Temperature

To compare the results for all cases where temperature readings were recorded at both the tube side outlet and the shell side outlet, it is essential to consider the variations in temperature under the specified inlet conditions of 50°C for the tube side and 15°C for the shell side.

Table 5.9: Comparison of Temperature Reduction on Tube Side and Temperature Increase on Shell Side for Various Baffle Configurations

C.No.	Baffle Configuration	Tube side TS	Shell side SS	% Reduction TS	% Accession SS
1	W/o Baffle	48.44	18.54	3.12	3.54
2	No Hole	44.75	19.14	10.494	4.14
3	Circular	44.57	19.90	10.856	4.90
4	Square	43.88	20.93	12.24	5.93
5	Elliptical horizontal	44.78	20.51	10.44	5.51
6	Triangle	43.57	24.40	12.852	9.40
7	Rhombus	44.18	20.70	11.646	5.70
8	Elliptical vertical	44.38	19.80	11.244	4.80

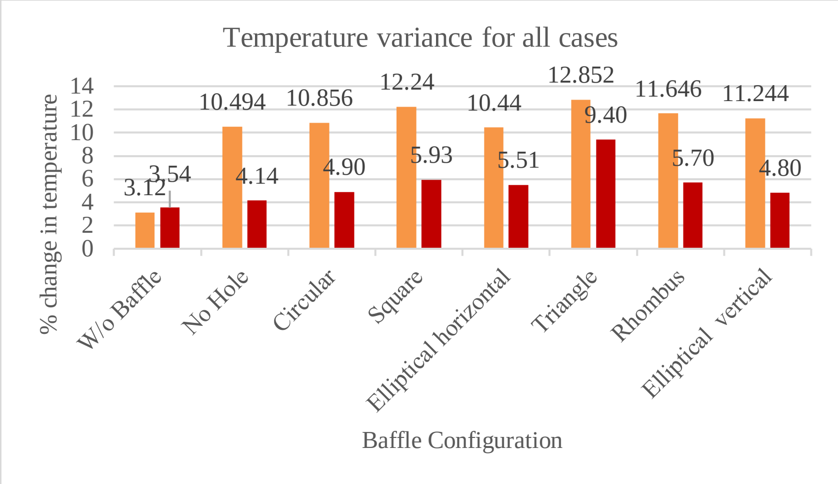

Figure 5.17 Comparative results for temperature

The different configurations of baffles in the DTHE are analyzed, showing temperature distributions and efficiency in heat transfer. In Case 1, without baffles, both the tube-side and shell-side temperature shows a base performance indicating only moderate reductions in temperature. Case 2, which has solid baffles, depicts a reduction of 10.44% in tube side temperature and 4.14% in shell side temperature, thus showing a considerable enhancement in heat transfer. Case 3, with baffles having circular holes, shows a reduction of 10.856% in tube side temperature and 4.90% in shell side temperature, thus proving a fact that circular perforations are quite effective in increasing the heat exchange. Case 4 shows a decrease of 12.24% in tube side temperature and a decrease of 5.93% in shell side temperature when square holes are used in the baffles, proving that square perforations enhance heat transfer to a great extent. Case 5 has horizontal elliptical holes and demonstrates a temperature drop of 10.50% on the tube side and 5.51% on the shell side, reflecting the positive effect of horizontal elliptic perforations on heat exchange efficiency. Case 6, with triangular holes, found the best configuration, drop of 12.852% in tube side and 9.40% on the shell side temperature rise, portraying better heat transfer performance. Case 7, which has rhombus-shaped perforations, causes an 11.646% reduction in tube side temperature and a 5.70% reduction in the shell side temperature. This shows that it has a positive effect on heat transfer. Case 8 has vertical elliptical holes; the reduction in temperature for this case is 11.244% on the tube side and 4.80% on the shell side—again proving that different designs on baffles affect the DTHE's heat transfer. The overall conclusion from the study is that there is an extraordinary effect of different baffle configurations on heat transfer, out of which triangular holes proved to be the best.

5.9.2 Comparative Results for Velocity

The recorded velocity readings at both the tube side outlet and shell side outlet provide crucial insights into how different baffle configurations impact fluid flow within the double-tube heat exchanger (DTHE). With consistent inlet velocities of 0.26 m/s for the tube side and 0.90 m/s for the shell side, variations in velocity profiles are observed as the fluids interact with the heat exchanger's internal components and baffles.

Table 5.10: Percentage Reduction in Temperature and Velocity for Various Baffle Configurations

C.No.	Baffle Configuration	Tube side TS	Shell side SS	% Reduction TS	% Reduction SS
1	W/o Baffle	0.38	0.950	46.15	5.56
2	No Hole	0.38	1.027	46.15	14.07
3	Circular	0.38	1.030	46.15	14.44
4	Square	0.37	1.080	42.31	20.00
5	Elliptical horizontal	0.38	1.029	46.15	14.31
6	Triangle	0.37	1.120	42.31	24.44
7	Rhombus	0.38	1.050	46.15	16.67
8	Elliptical vertical	0.38	1.040	46.15	15.56

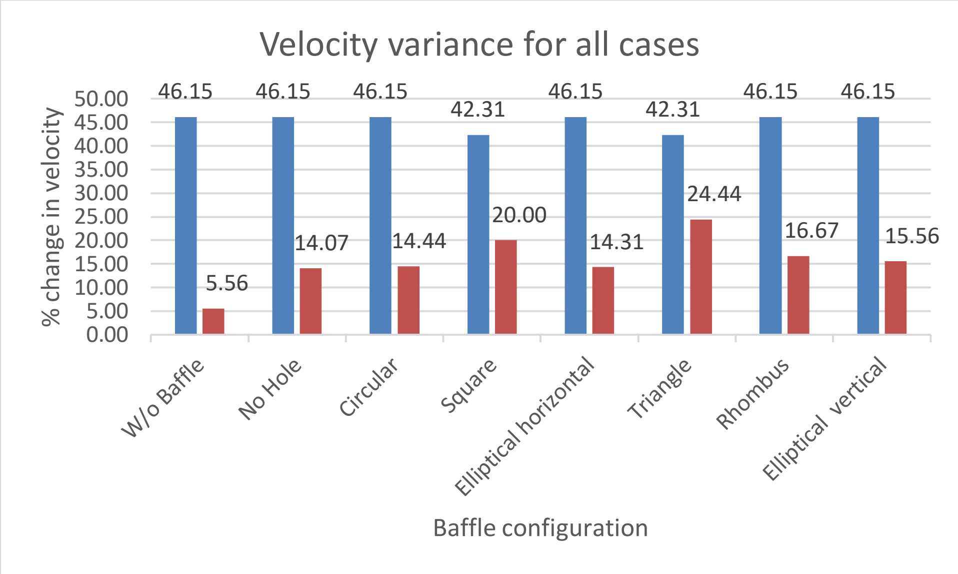

Figure 5.18 Comparative results for velocity

The examination of fluid velocity changes at both the tube side and shell side of the double-tube heat exchanger (DTHE) highlights the effects of various baffle configurations on fluid dynamics. In the baseline scenario without baffles (Case 1), the tube side velocity is 0.38 m/s and the shell side velocity is 0.950 m/s. Introducing simple baffles with no perforations (Case 2) improves the velocities, resulting in 0.38 m/s on the tube side and 1.027 m/s on the shell side. The addition of circular holes in the baffles (Case 3) further increases fluid velocities, with 0.38 m/s on the tube side and 1.030 m/s on the shell side. Square holes in the baffles (Case 4) show even greater improvement; with a tube side velocity of 0.37 m/s and a shell side velocity of 1.080 m/s. Triangular holes (Case 6) achieve the highest performance, with a tube side velocity of 0.37 m/s and a shell side velocity of 1.120 m/s, indicating superior fluid flow characteristics. These results illustrate the significant influence of baffle design on enhancing fluid flow efficiency in the DTHE.

VI. CONCLUSION

The conclusion of the present study points out that the segmental perforated baffles have immense influence on the thermal performance of double pipe heat exchangers. That means, on aspects of improving heat transfer efficiency, geometry and configurations of these baffles are playing a major role, as evident from both experimental analysis and CFD simulations. Out of several designs tested, triangular perforations in the baffles revealed the highest efficiency, where a notable reduction in tube-side temperature, with an increased temperature on the shell side, was caused. This might mean that the shape particular to the perforations creates more turbulence and thus enhances fluid mixing to optimize heat transfer within the heat exchanger. The study further comments that the introduction of perforated baffles in the system improves the thermal performance and has some positive effects on fluid velocity. Having this dual improvement in heat transfer and fluid flow makes perforated baffles a rather valuable device, especially in applications where space, efficiency, and pressure drop become key factors. These results have proved that proper optimization in design of these baffles may drastically enhance performance in double-pipe heat exchangers, making industrial processes much more effective. Future scope in this area may be attributed to other geometric variations and material choices to further refine and enhance efficiency.

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