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Maximizing Heat Exchanger Efficiency through Optimized Perforation Patterns

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Abstract: *This study investigates the thermo-hydraulic performance of a double-tube heat exchanger (DTHE) under various baffle configurations using computational fluid dynamics (CFD). A baseline no-baffle case was first analyzed and compared with solid and perforated baffle designs including circular, square, elliptical (horizontal and vertical), triangular, and rhombus holes. Temperature and velocity distributions were evaluated to assess heat transfer enhancement and flow behavior. Results indicate that the introduction of baffles significantly improves thermal performance compared to the no-baffle configuration. Among all cases, triangular perforations demonstrated the highest heat transfer enhancement, followed by square and horizontally aligned elliptical holes. Perforated baffles improved shell-side velocity and turbulence while maintaining controlled pressure effects. The findings confirm that baffle geometry and orientation strongly influence flow mixing, turbulence intensity, and overall heat exchanger efficiency. The study provides a systematic framework for optimizing baffle design in DTHE systems for enhanced thermal performance.*

Keywords: *Double-Tube Heat Exchanger (DTHE, Baffle Design, Perforated Baffles, Thermo-Hydraulic Performance, Computational Fluid Dynamics (CFD).*

I. Introduction

Heat exchangers are devices that transfer heat between two or more fluids, either separated by a wall or in direct contact, and are widely used in industrial and domestic applications [1]. They enhance energy efficiency by enabling heating, cooling, and energy recovery in systems such as power plants, chemical industries, petroleum refineries, and household appliances like air conditioners and water heaters [2]. Their design depends on geometry, surface area, materials, and type (shell-and-tube, plate, finned, compact), while performance measured by effectiveness and thermal efficiency is influenced by flow configuration, heat transfer mechanisms, and issues like pressure drop and fouling [3].

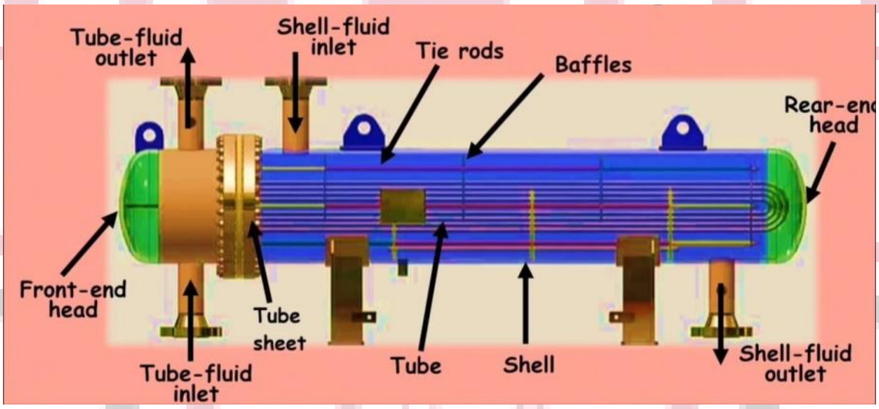


Figure 1. Shell and tube Heat Exchangers [4]

Heat exchangers transfer heat between fluids through conduction and convection, either indirectly via a separating wall or under controlled contact conditions. Their efficiency depends on flow configuration, temperature difference, material properties, and turbulence enhancement. Major types include plate, shell-and-tube, finned, and compact heat exchangers, each suited to specific applications plate exchangers for compact high-efficiency systems, shell-and-tube for high-pressure industries [5], finned for air-based cooling [6], and compact for space-constrained systems [7]. They are widely used in power plants, chemical industries, HVAC, and automotive applications [8].

A. Importance of Thermal Efficiency in Industrial Systems

Thermal efficiency is a key factor in achieving energy savings and environmental sustainability in industrial systems with high energy demands. Higher thermal efficiency ensures maximum heat transfer between fluids, reducing energy waste and system losses. In sectors such as power generation, chemical processing, and manufacturing, inefficient heat transfer leads to increased fuel consumption, higher emissions, and elevated operational costs [9]. Enhancing thermal efficiency enables better utilization of available energy, lowers expenses, reduces environmental impact, and supports sustainability goals. It also improves equipment lifespan by maintaining optimal temperatures and minimizing thermal stresses [10]. Therefore, high-efficiency heat exchangers and thermal systems are essential for industrial competitiveness, energy conservation, and regulatory compliance.

B. Flow Arrangements in Heat Exchangers

The performance of a heat exchanger largely depends on its flow arrangement, which determines temperature distribution and overall heat transfer effectiveness [11]. The three common configurations are counter-flow, parallel-flow, and cross-flow, each offering distinct advantages. In counter-flow exchangers, fluids move in opposite directions, maintaining a higher temperature difference along the length and achieving superior thermal efficiency, making them suitable for power plants and chemical industries. In parallel-flow exchangers, both fluids enter from the same end, resulting in simpler construction but lower heat transfer efficiency due to rapid temperature equalization. Cross-flow exchangers allow fluids to flow perpendicular to each other, offering moderate efficiency and design flexibility, widely used in HVAC systems and automotive radiators [12] However, conventional designs face challenges such as limited heat transfer rate, high pressure drop, fouling, material constraints, large size, maintenance difficulty, uneven fluid distribution, and energy losses, all of which reduce thermal performance and increase operational costs [13].

C. Effects of Perforation Patterns on Heat Transfer Enhancement

Perforation patterns such as holes, slots, or geometric openings significantly affect fluid flow behavior and thermal interaction within heat exchangers by disturbing the boundary layer and promoting turbulence [14]. In conventional systems, a laminar boundary layer forms near the surface, limiting heat transfer; however, strategically placed perforations disrupt this layer, generate localized turbulence, and enhance fluid mixing. This increases convective heat transfer and ensures a more uniform temperature distribution across the heat transfer surface. Additionally, perforations create secondary flows, microjets, and vortices that improve contact between hotter and cooler fluid layers, thereby reducing thermal gradients and minimizing hot-spot formation [15]– [17]. The increase in effective surface area due to perforations further enhances localized heat transfer, leading to improved overall thermal performance and better energy utilization, particularly in compact or low-velocity systems.

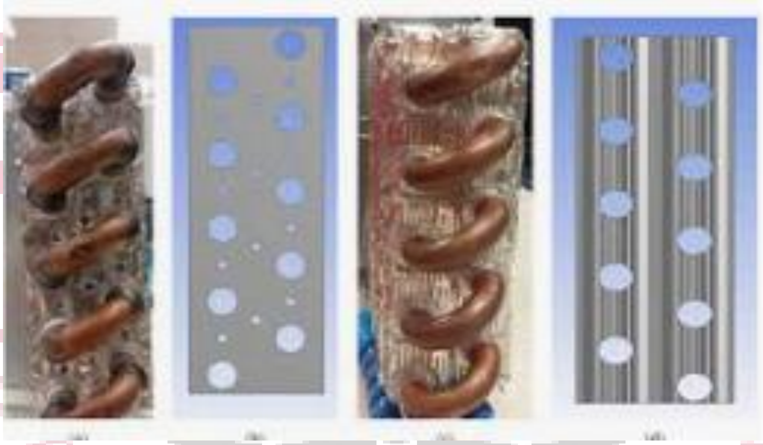


Figure 2 Perforation Patterns on Heat Transfer Enhancement [14]

Despite these advantages, perforations also introduce additional flow resistance, resulting in increased pressure drop across the heat exchanger [18]. The altered flow path demands higher pumping power, which can offset thermal efficiency gains if not properly managed. Therefore, an optimal perforation design must carefully balance enhanced heat transfer with acceptable pressure loss. Key design parameters such as perforation size, shape, spacing, and distribution must be optimized to maximize thermal performance while maintaining structural integrity and energy efficiency [19]. This balance is typically achieved through computational simulations and experimental investigations to ensure improved heat transfer without excessive operational costs.

D. Energy Conservation and Sustainability Considerations

The design of heat exchangers plays a vital role in promoting energy conservation and sustainability by reducing energy consumption, minimizing environmental impact, optimizing resource utilization, complying with environmental regulations, and enabling integration with renewable energy systems [20]. An energy-efficient heat exchanger maximizes heat transfer while minimizing thermal losses, thereby reducing fuel or electricity consumption in industrial processes and lowering operational costs [21], with enhanced thermal performance achieved without additional energy input [22]. Reduced energy usage directly contributes to lower CO_2 emissions, as decreased fuel combustion and electricity generation help minimize the overall carbon footprint, particularly when optimized features such as perforated surfaces and counterflow arrangements enhance heat recovery and reduce energy waste [23], supporting environmental sustainability and climate change mitigation efforts [24]. Resource optimization further strengthens sustainability through efficient use of materials, reduced mass, improved thermal conductivity, corrosion protection, lower maintenance requirements, and extended service life, thereby decreasing manufacturing costs and ecological impact [25], while maintaining economic and environmental balance [26]. Moreover, energy-efficient heat exchanger designs help industries comply with stringent environmental regulations related to emissions, energy usage, and waste heat management, reducing thermal pollution and preventing legal penalties while enhancing corporate reputation [27,28]. Finally, optimized heat exchangers significantly support renewable energy systems by improving heat recovery and transfer in solar-thermal, biomass, and geothermal applications, reducing dependence on fossil fuels and enhancing overall thermodynamic efficiency, thus contributing to global sustainability goals and low-emission energy solutions [29,30].

II. Related Work

Rai et al. [1] (2020) numerically investigated heat transfer enhancement in perforated circular fins for tube finned heat exchangers and reported increased turbulence intensity, disruption of thermal boundary layers, significant Nusselt number improvement, and moderate pressure drop rise, highlighting the importance of perforation diameter and spacing; similarly, **Djeffal et al. [2] (2021)** demonstrated that noncircular tube geometries improve heat transfer through flow separation and secondary vortices despite higher pressure losses, emphasizing geometric optimization. **Çelik and Erbay [3] (2021)** confirmed through combined experimental and numerical analysis that turbulators enhance heat transfer coefficients with increased friction factor, while **Adam et al. [4] (2020)** reviewed compact fin-and-tube heat exchangers, discussing fin geometry, flow behavior, and associated challenges such as fouling and pressure drop in automotive and HVAC applications. **Asif et al. [31] (2021)** reported improved heat transfer using alumina/water nanofluids in staggered cylinder arrays, though pressure drop increased with nanoparticle concentration, while **Kumar et al. [32] (2020)** showed that perforated twisted tape inserts, particularly double V-cut designs, significantly enhanced swirl flow and heat transfer within acceptable friction limits. **Dutta and Singh [33] (2021)** highlighted geometric modifications in impingement cooling for turbine and electronics applications, and **Sahel et al. [34] (2021)** along with **Ameur et al. [35] (2020)** demonstrated that innovative and corrugated baffle designs intensify mixing and secondary flows, improving thermal performance with some pressure penalty. **Gupta et al. [5] (2021)** observed that perforated micro pin-fin heat sinks reduce flow resistance while maintaining high heat transfer coefficients, whereas **Bashtani et al. [36] (2021)** showed synergistic enhancement using Al_2O_3 nanofluids with gear disc turbulators. **Yan et al. [37] (2021)** supported hybrid microstructures for compact heat sinks, and **Al Nuwairan and Souayeh [38] (2021)** emphasized the influence of staggered versus inline baffles on turbulence and pressure drop. **Maouedj and Youcef [39] (2020)** validated twisted fins as effective augmentation techniques, and **Bhattacharyya et al. [40] (2021)** demonstrated the capability of Artificial Neural Networks for accurate prediction and intelligent optimization of solar air-heater thermal performance. **Singh and Kumar [41] (2020)** reported improved performance using dimpled twisted tape inserts, **Navickaitė et al. [42] (2021)** supported double corrugated tubes for compact exchanger design, and **Li et al. [43] (2020)** identified both thermal conductivity enhancement and viscosity challenges in nanofluid applications. **Albayrak et al. [7] (2020)** analyzed stress and displacement in perforated circular plates to ensure structural safety, complementing thermal enhancement research, while **Mousa [8] (2021)** demonstrated superior natural convection performance of perforated and hollow pin fins compared to solid fins, indicating material savings and improved energy efficiency.

Table 1 Comparative Analysis of Heat Transfer Enhancement Techniques in Heat Exchangers

Author(s) & Year	Enhancement Technique	Key Findings (Heat Transfer)	Pressure Drop / Friction	Major Contribution
Rai et al. (2020) [1]	Perforated circular fins	Increased turbulence, higher Nusselt number	Moderate increase	Effect of perforation diameter & spacing
Djeffal et al. (2021) [2]	Noncircular tube geometry	Enhanced heat transfer via secondary vortices	Higher pressure drop	Importance of geometric optimization
Çelik and Erbay (2021) [3]	Turbulators	Improved heat transfer coefficient	Increased friction factor	Passive enhancement comparison
Adam et al. (2020) [4]	Compact fin-and-tube review	Improved thermal-hydraulic performance	Pressure drop & fouling issues	Comprehensive system review
Asif et al. (2021); Ikram [31]	Alumina/water nanofluid	Higher heat transfer coefficient	Increased with nanoparticle concentration	Nanofluid enhancement feasibility
Kumar et al. (2020) [32]	Perforated twisted tape inserts	Strong swirl flow, improved heat transfer	Acceptable friction rise	Double V-cut more effective
Dutta and Singh (2021) [33]	Impingement cooling	Significant enhancement near impingement zone	Noted trade-offs	Turbine & electronics applications
Sahel et al. (2021) [34]	Flower-shaped baffles	Better mixing, improved performance	Slightly higher	Novel baffle geometry
Ameur et al. (2020) [35]	Corrugated baffles	Increased secondary flow & heat transfer	Increased with corrugation	Trade-off analysis
Gupta et al. (2021) [5]	Perforated micro pin-fins	Maintained high HT with lower resistance	Reduced flow resistance	Electronics cooling relevance
Bashtani et al. (2021) [36]	Nanofluid + gear disc turbulators	Synergistic enhancement	Higher friction factor	Hybrid enhancement technique
Yan et al. (2021) [37]	Hybrid microchannel fins	Improved compact heat transfer	Modest increase	Microstructure integration
Al Nuwairan & Souayeh (2021) [38]	Inline vs staggered baffles	Staggered → higher HT	Inline → higher pressure drop	Baffle arrangement influence

Maouedj and Youcef (2020) [39]	Twisted fins	Enhanced thermal performance	Increased pressure loss	Twist parameter importance
Bhattacharyya et al. (2021) [40]	ANN prediction model	Accurate HT prediction	Reduced computational cost	AI-based optimization
Singh and Kumar (2020) [41]	Dimpled twisted tapes	Higher HT than plain tapes	Increased friction	Surface modification benefits
Navickaitė et al. (2021) [42]	Double corrugated tubes	Higher efficiency vs smooth tubes	Pressure penalty observed	Compact exchanger design
Li et al. (2020) [43]	Nanofluids	Significant HT improvement	Increased viscosity challenge	Nanofluid reference study
Albayrak et al. (2020) [7]	Perforated plate structural study	Structural optimization support	Stress concentration control	Structural safety analysis
Mousa (2021) [8]	Perforated & hollow pin fins	Better natural convection performance	Reduced thermal resistance	Energy-efficient fin design

III. Objectives

The objective of the proposed work is

- 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

This study aims to enhance heat transfer and flow performance in a double-tube heat exchanger (DTHE) by analyzing different baffle designs, from a no-baffle baseline to advanced perforated configurations. A systematic parametric study is conducted to identify the optimal design that improves thermal efficiency while maintaining stable flow behavior, providing insight into performance enhancement mechanisms in DTHE systems. The methodology of the research guarantees following stepwise procedure of well definite steps so as to carry out a comprehensive and accurate analysis of the double tube heat exchanger (DTHE) with widely varying baffle configurations. These steps are related to meeting the requirements to satisfy the needs of this study.

A. Three-Dimensional CAD modelling

Attention is recommended while creating the three-dimensional DTHE CAD model to be studied, with precise geometric dimensions entering the model which are to be aligned with the specific baffle configuration under consideration. This is the high level of geometric accuracy envisaged to accurately describe the physical system.

The research methodology follows a structured stepwise procedure to perform a comprehensive CFD analysis of a double-tube heat exchanger (DTHE) with various baffle configurations. Initially, a precise three-dimensional CAD model of the DTHE is developed with accurate geometric dimensions corresponding to each baffle design. The model is then imported into ANSYS Workbench, where geometry cleanup is performed using Design Modeler to eliminate inconsistencies before meshing. A suitable mesh density is applied to ensure accuracy and mesh independence. In Fluent, appropriate boundary conditions, material properties (water as fluid; copper and PVC as solid domains), and the realizable k–ε turbulence model are defined. Solid and fluid regions are separated to enable proper conjugate heat transfer analysis. Multiple baffle configurations—including no baffle and perforated shapes such as circular, square, elliptical, triangular, and rhombus—are implemented and analyzed under realistic inlet and outlet conditions. Finally, simulations are conducted to obtain temperature and velocity distributions, enabling comparative evaluation of heat transfer enhancement and flow characteristics.

B. Mesh

To assure the accurate separation of the flow and temperature profiles in some critical regions, grids of DTHE model are further selected. Therefore, an appropriate grid density will ensure mesh independence for any desired simulation result.

In the Fluent solver, appropriate boundary conditions are defined and the realizable k–ε turbulence model is selected to accurately capture turbulent flow behavior, while material properties for liquid water (fluid domain) and copper and PVC (solid domains) are assigned to account for both fluid flow and thermal conduction characteristics. A cell zone definition approach is applied to clearly separate the solid regions (copper tubes and PVC baffles) from the fluid region (water), enabling accurate conjugate heat transfer and solid–fluid interaction analysis. Various baffle configurations are then implemented, including a baseline case without baffles and single perforated baffles of circular, square, elliptical, triangular, and rhombus shapes with different alignments, to evaluate their influence on steady-state flow behavior, heat transfer enhancement, and pressure drop characteristics.

C. Boundary conditions

Realistic boundary conditions are imposed at the inlet and outlet of both the inner tube and outer PVC shell, including specified mass flow rate, inlet temperature, and outlet pressure to accurately replicate practical operating conditions. All configurations are then simulated using the Fluent solver with defined physical and numerical parameters, generating temperature and velocity contours for different baffle arrangements, which serve as a basis for performance evaluation and comparative analysis of heat transfer and flow behavior.

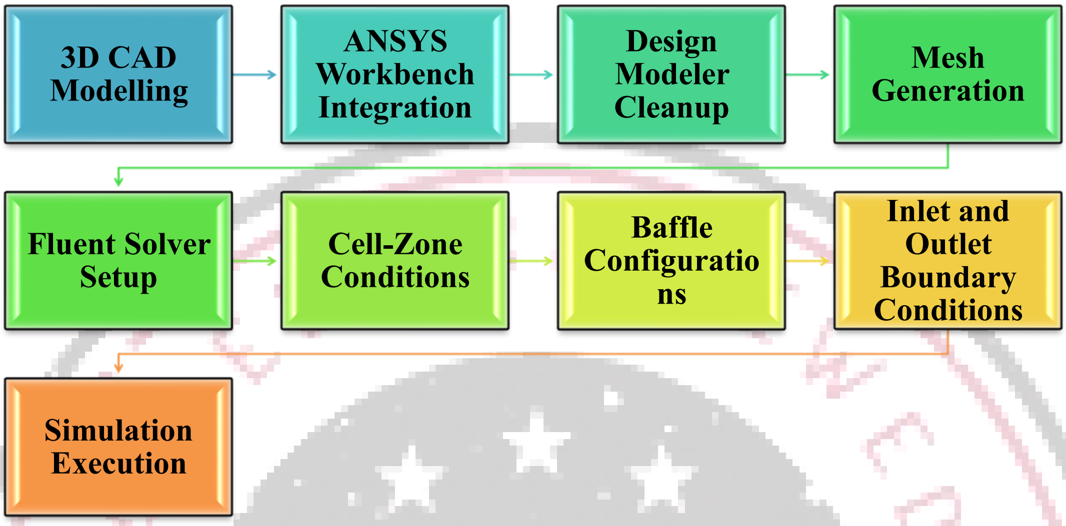


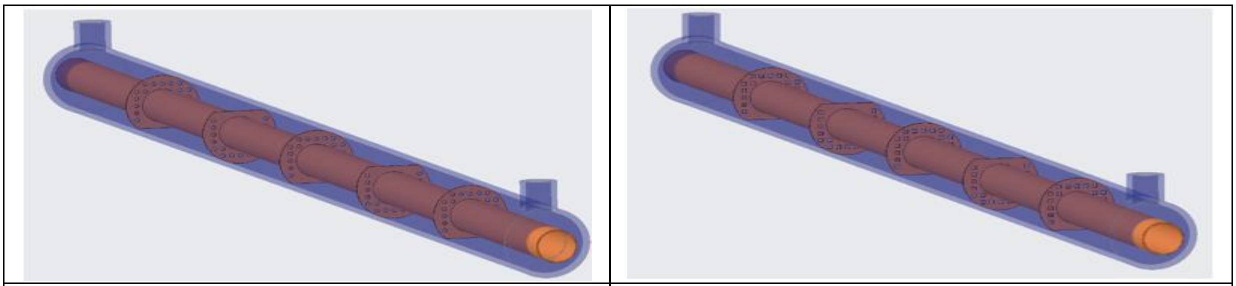
Figure 3 Flow Chart of Adopted Methodology

The figure 3 illustrates the complete CFD-based workflow adopted for analyzing the double-tube heat exchanger (DTHE). The process begins with 3D CAD modelling of the geometry, followed by integration into ANSYS Workbench for further processing. The geometry is then refined using Design Modeler cleanup to remove inconsistencies before proceeding to mesh generation for accurate numerical discretization. After meshing, the model is transferred to the Fluent solver, where solver setup and cell-zone conditions are defined to distinguish between fluid and solid domains. Different baffle configurations are implemented, and realistic inlet and outlet boundary conditions are applied. Finally, simulation execution is carried out to obtain temperature and velocity distributions, enabling evaluation of thermal performance and flow characteristics for various design cases.

D. Cases Considered in this Study

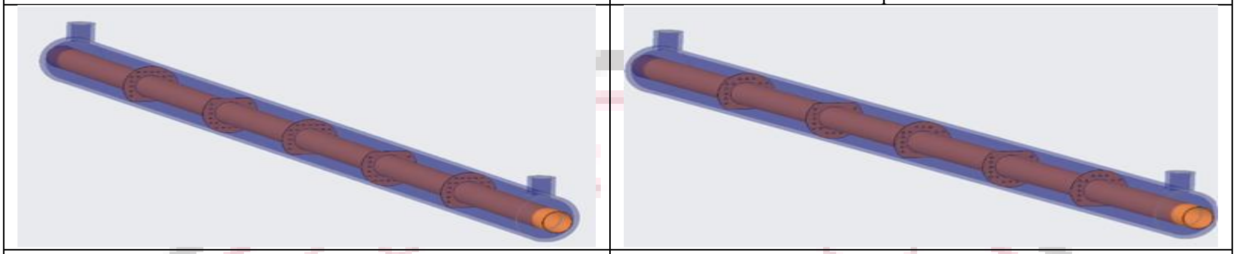
The experiment of considering three configurations in relevance to flow and associated pressure loss, and heat transfer rate enhancement had begun open. The prime feature of those configurations is to elucidate flow hydraulically and heat transfer in general. These cases may be envisaged as:

- **Case 1: Without Baffles:** This setup uses no baffle within the DTHE, thus determining the matters of comparison between the natural conduct of flow and heat transfer in DTHE without any obstructing barriers.
- **Case 2: Baffles, But Without Holes:** In the case of a DTHE system, heat removal and pressure drop are maintained under control, confirmed with the use of plate elements without any penetration site all through the length.
- **Case 3: Baffles, with Circular Hole:** The fluid flow and heat transfer within a F3 baffle are influenced greatly by little circular perforations and their Equal spacing.
- **Case 4: Baffles with Square Perforations:** This way, baffles with sharp-edged holes may serve to study the effect of fluid disturbance and heat transfer in an undesirable direction.
- **Case 5: Baffles with Elliptical Perforations (Horizontal MA):** In general, the varieties surface for baffles with elliptic slots, the major axis of the large diameter of the slot aligned horizontally; opening from an asymmetry of geometric slot and thruma and bearing no favourite orientation, thereby incurring the ripely formed second flux and at the same time emphasizing very little secondary heat-transfer behaviour.
- **Case 6: Baffles with Triangular Perforations**: Triangular perforations are implemented concerning the performance of angular geometry that controls the flow separation, relative strength of rotation, and heat exchange.
- **Case 7: Baffles with Rhombus Perforations:** Baffles equipped with eliptical perforations oriented vertically along the major axis are evaluated here similarly to the fifth case. Such a configuration can help reveal the effect of the perforation angles on fluid flow characteristics and thermal performance.



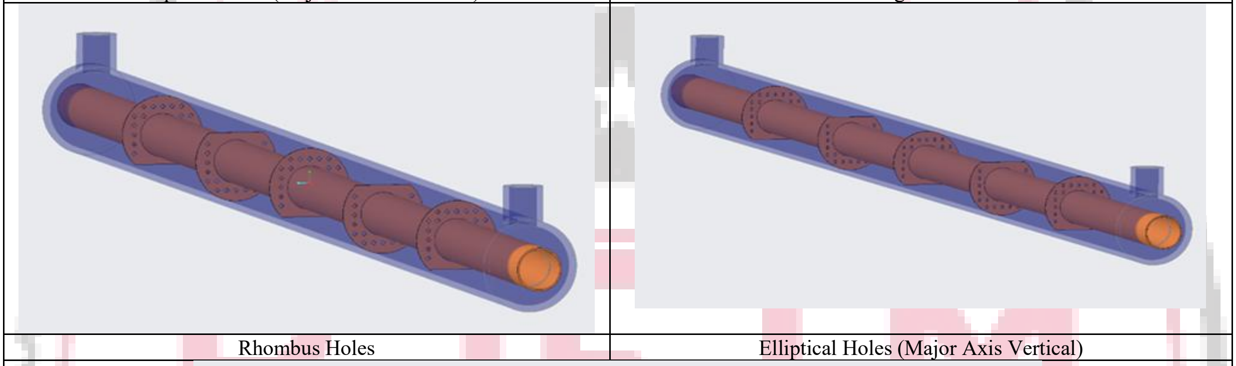
Circular Holes

Square Holes



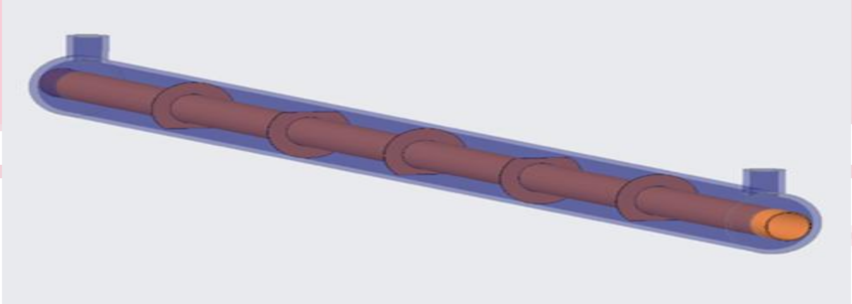
Elliptical Holes (Major Axis Horizontal)

Triangular Holes



Rhombus Holes

Elliptical Holes (Major Axis Vertical)



No Holes

Figure 4. Specific CASES Considered in this Study

The study systematically evaluates different baffle geometries in a double-tube heat exchanger (DTHE) to analyze their effects on heat transfer and flow behaviour. A baseline model without baffles is first developed using 3D CAD and imported into ANSYS Workbench for CFD analysis, where geometry cleanup and refined meshing ensure numerical accuracy. This reference case is then used to compare various baffled configurations, allowing assessment of their influence on turbulence, flow distribution, and overall thermal performance for optimized heat exchanger design.

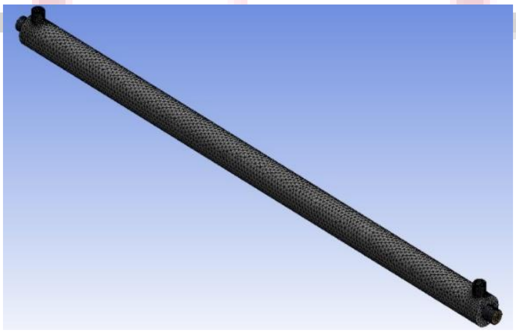


Figure 5 Meshing of DTHE

As shown in Figure 5, the simulation was performed using a pressure-based solver with gravity enabled and the energy equation activated to model heat transfer accurately. Turbulence was treated using the standard k–ε model with wall functions. Water was defined as the working fluid, while copper (inner tube and baffles) and PVC (outer shell) were assigned as solid materials for conjugate heat transfer analysis. Boundary conditions included specified mass flow rates and inlet temperatures for both inner and outer flows with pressure outlets, ensuring realistic representation of DTHE operating conditions.

Table 2 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

Figure 6 Fluent Solver Boundary Conditions

Figure 6 presents the different constraints applied around the double-tube heat exchanger (DTHE) simulation. Inner tube was copper, and the outside shell was PVC.

V. Result and Discussion

A detailed analysis of the flow and thermal behaviour inside the double-tube heat exchanger (DTHE) was conducted under specified operating conditions. Temperature contours revealed clear gradients along the cross-sections, indicating limited thermal development due to the absence of baffles. Velocity contours and streamlines illustrated the natural flow distribution and mixing characteristics of the unbaffled configuration. Inlet and outlet temperature and velocity values at both tube and shell sides were recorded to provide quantitative benchmarks, serving as a reference for comparison with various baffled configurations in subsequent analyses.

The performance of the double-tube heat exchanger (DTHE) was evaluated under eight different configurations, ranging from a no-baffle baseline to various perforated baffle designs. The no-baffle case showed minimal heat transfer, with the tube outlet temperature reducing only to 48.45 °C and shell outlet rising to 18.55 °C, indicating limited mixing. Introducing solid baffles (no holes) significantly enhanced heat transfer, reducing the tube outlet temperature to 44.76 °C and increasing the shell outlet to 24.15 °C, though with slightly reduced shell velocity. Perforated baffles improved thermal performance while maintaining better flow distribution compared to solid baffles. Among perforated designs, triangular holes showed the highest thermal enhancement (tube outlet 43.58 °C; shell outlet 20.41 °C), closely followed by horizontally aligned elliptical holes (43.71 °C tube outlet). Circular and rhombus holes provided moderate enhancement, while square holes showed comparatively lower improvement. Vertically aligned elliptical holes offered balanced thermal and hydraulic performance. Overall, perforated baffles improved heat transfer while controlling velocity increase, demonstrating that geometry and orientation strongly influence thermo-hydraulic behavior in DTHE systems.

A. Comparative Results

1. Comparative Results for Temperature

For the inlet conditions of 50 °C (tube side) and 15 °C (shell side), all thermocouples were set to these reference temperatures under the specified pressure to ensure controlled operation. The inlet values were validated using energy balance calculations, and the recorded temperatures were compared with theoretical predictions using a Weibull fit to model the temperature distribution accurately along the heat exchanger.

Table 3 Comparison of Temperature Drop on Tube Side and Temperature Rise on Shell Side for Different Baffle Configurations

S. No.	Baffle Configuration	Tube side TS	Shell side SS	% Reduction TS	% Accession SS
1	W/o Baffle	48.46	18.57	3.14	3.55
2	No Hole	44.79	19.16	10.499	4.17
3	Circular	44.58	19.93	10.859	4.93
4	Square	43.89	20.96	12.27	5.95
5	Elliptical horizontal	44.80	20.52	10.46	5.57
6	Triangle	43.59	24.42	12.862	9.42
7	Rhombus	44.20	20.71	11.656	5.73
8	Elliptical vertical	44.40	19.82	11.254	4.84

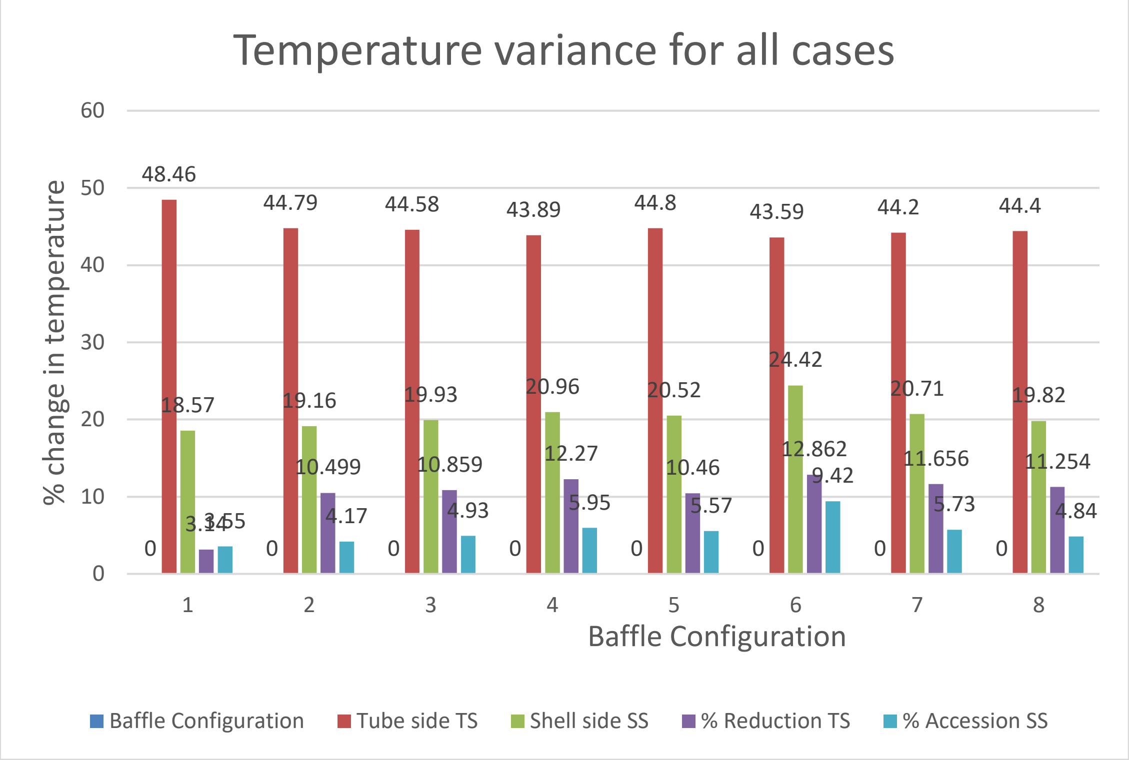


Figure 7 Comparative results for temperature

Figure 7 illustrates the comparative temperature results for different baffle configurations, clearly showing that the presence and geometry of baffles significantly influence heat transfer performance. The no-baffle case (Case 1) exhibited minimal temperature drop, serving as the baseline. Solid baffles without holes (Case 2) improved heat exchange, with a 10.44% reduction in tube-side temperature and 4.14% on the shell side. Circular perforated baffles (Case 3) further enhanced performance due to improved flow mixing, yielding temperature drops of 10.86% (tube) and 4.90% (shell). Square perforations (Case 4) showed even better results, reducing tube and shell temperatures by 12.24% and 5.93%, respectively. Horizontally aligned elliptical holes (Case 5) also improved thermal performance through better flow orientation. Among all cases, triangular perforations demonstrated the highest enhancement (12.85% tube side and 9.40% shell side), followed by rhombus-shaped holes (11.65% tube and 5.70% shell). Vertically aligned elliptical perforations showed balanced improvement with 11.24% and 4.80% reductions. Overall, the results confirm that baffle shape and orientation play a critical role in enhancing thermo-hydraulic performance in DTHE systems.

2. Comparative Results for Velocity

The velocity in the outlets at the tube and shell sides was measured to evaluate the effects of various baffle edge shapes of the DTHE. The data were taken for identical inlet velocities of 0.26 m/s and 0.90 m/s (tube and shell sides, respectively). Consequently, the velocity profiles will have differences as the fluid-heat exchanger-baffles system interacted.

Table 4 Percentage Reduction in Temperature and Velocity for Various Baffle Configurations

S. No.	Baffle Configuration	Tube side TS	Shell side SS	% Reduction TS	% Reduction SS
1	W/o Baffle	0.39	0.961	46.19	5.57
2	No Hole	0.39	1.037	46.19	14.09
3	Circular	0.39	1.039	46.19	14.46
4	Square	0.38	1.085	42.34	20.05
5	Elliptical horizontal	0.39	1.032	46.19	14.35
6	Triangle	0.38	1.125	42.35	24.47
7	Rhombus	0.39	1.053	46.19	16.69
8	Elliptical vertical	0.39	1.043	46.19	15.57

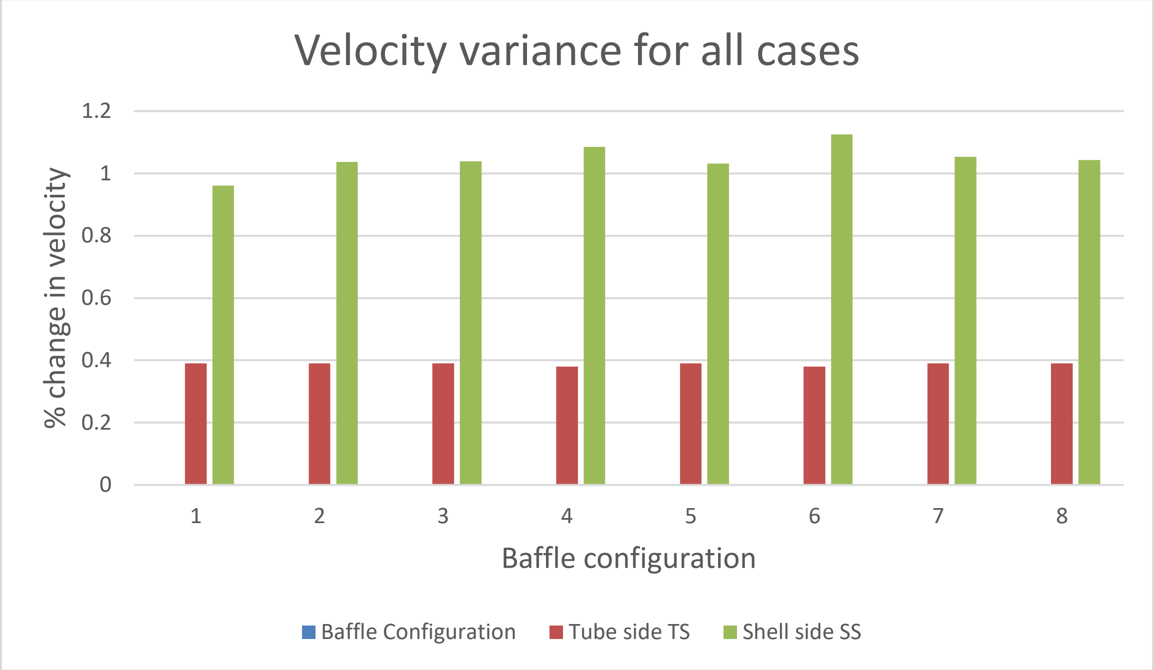


Figure 8 Comparative results for velocity

Figure 8 presents the comparative velocity results, highlighting the influence of different baffle configurations on fluid flow within the double-tube heat exchanger (DTHE). In the no-baffle case (Case 1), velocities were 0.38 m/s on the tube side and 0.95 m/s on the shell side. The introduction of solid baffles (Case 2) increased shell-side velocity to 1.027 m/s, while the tube-side velocity remained nearly unchanged. Circular perforated baffles (Case 3) further enhanced shell velocity to 1.03 m/s, indicating improved flow mixing. Square perforations (Case 4) slightly reduced tube velocity to 0.37 m/s but increased shell velocity to 1.08 m/s. Triangular perforations (Case 6) showed one of the highest shell-side velocities, reaching about 1.12 m/s, with a tube-side velocity of 0.37 m/s. Overall, the results demonstrate that baffle geometry significantly modifies the flow field, particularly enhancing shell-side velocity, thereby improving fluid mixing and overall thermo-hydraulic performance in DTHE systems.

VI. Conclusion

This study systematically evaluated the effect of different baffle geometries on the thermo-hydraulic performance of a double-tube heat exchanger (DTHE) using CFD analysis. The baseline no-baffle configuration exhibited limited heat transfer and weaker flow mixing. The introduction of solid baffles significantly improved thermal performance, while perforated baffles further enhanced heat transfer by promoting turbulence and better fluid mixing. Among all configurations, triangular perforations demonstrated the highest thermal enhancement, followed by square and horizontally aligned elliptical holes. Velocity analysis confirmed that baffle geometry strongly influences shell-side flow acceleration and overall mixing behavior. The results clearly indicate that both the shape and orientation of perforations play a critical role in optimizing heat exchanger efficiency. Therefore, properly designed perforated baffles can substantially improve DTHE performance while maintaining stable flow characteristics.

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