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CFD-BASED COMPARATIVE ANALYSIS OF TUBE GEOMETRY AND BAFFLE DESIGN ON SHELL-AND-TUBE HEAT EXCHANGER PERFORMANCE USING SOLIDWORKS

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Abstract— Shell-and-tube heat exchangers (STHEs) continue to dominate industrial applications because of their durability and adaptability across a wide range of operating conditions. As the push for higher energy efficiency intensifies, the use of Computational Fluid Dynamics (CFD) has become increasingly valuable for enhancing exchanger designs, supplementing and surpassing conventional analytical techniques. In this research, a comparative evaluation was carried out between two tube geometries—circular and square—in combination with two baffle arrangements: the traditional segmental type and the disk-and-doughnut design. Simulations were performed using SolidWorks Flow Simulation to assess steady-state thermal performance, focusing on outlet temperatures for both the shell-side and tube-side fluids. The ε–NTU method was then applied to determine exchanger effectiveness. The results indicate that the circular tube paired with a segmental baffle yielded the best performance (ε = 0.824), while the square tube with a disk-and-doughnut baffle produced a lower yet acceptable efficiency (ε = 0.752). Overall, the findings confirm that the interaction between tube geometry and baffle configuration plays a decisive role in the thermal characteristics of STHEs, emphasizing the need for their combined optimization in future designs.
Keywords— Computational Fluid Dynamics (CFD), Shell-and-Tube Heat Exchanger (STHE), Tube Geometry, Baffle Design, Heat Transfer Efficiency, Pressure Drop, Thermal Performance, Energy Optimization**.**

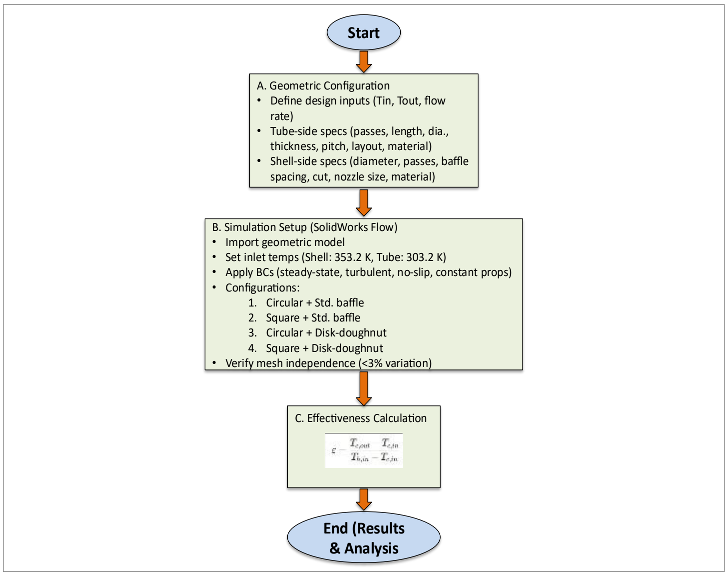
INTRODUCTION

Shell-and-tube heat exchangers (STHEs) are extensively employed in industries such as oil and gas, chemical processing, and power generation because of their capacity to withstand extreme operating conditions [1], [6], [9]. Traditionally, STHEs have been designed using the Log Mean Temperature Difference (LMTD) method or the Effectiveness–NTU approach. However, advances in Computational Fluid Dynamics (CFD) tools—such as ANSYS Fluent, COMSOL Multiphysics, and SolidWorks Flow Simulation—now enable more accurate performance prediction [2], [3], [14].
Among the numerous design parameters of STHEs, tube geometry and baffle configuration are two of the most critical. Circular tubes are the conventional choice due to ease of fabrication and mechanical stability, while non-circular tubes (e.g., square, hexagonal) can enhance turbulence and surface area, leading to improved thermal transfer [11], [16]. On the shell side, baffles guide fluid flow and reduce stagnation. Standard segmental baffles are most common, though disk-and-doughnut baffles have shown advantages in pressure drop reduction and flow uniformity [4], [6].
Despite numerous studies on these individual features, limited research has focused on their combined influence. This study addresses that gap by analyzing circular and square tube geometries with standard and disk-and-doughnut baffles using CFD simulations.

METHODOLOGY

A. Methodology Flowchart

Figure 1. Methodology Flowchart.



B. Geometry Configuration

Table 1. Geometry Specification

Design Inputs	
Hot water inlet temperature	80 °C
Cold water inlet temperature	30 °C
Flow rate (each side)	30 m³/h
Tube-side specifications (1-pass)	
Number of tube passes	1 (straight-through)
Tube length	3m
Tube outer diameter	19.05 mm (¾")
Tube wall thickness	1.24 mm (16 BWG)
Tube pitch	25 mm (1")
Tube layout	Triangular pitch, 45°
Tube material	Stainless Steel 321
Shell-side specifications	
Shell diameter	450 mm
Shell material	Stainless Steel 321
Shell passes	1 (crossflow)
Baffle spacing	200 mm
Standard baffle cut	25%
Nozzle size	4" (100 mm)

C. Simulation Setup

The study employed SolidWorks Flow Simulation to model a single-pass shell-and-tube exchanger operating under water-to-water heat recovery conditions.

- Inlet Temperatures:
  - Shell side: 353.2 K
  - Tube side: 303.2 K
- Simulated Configurations:

1. Circular tube + Standard segmental baffle

2. Square tube + Standard segmental baffle
3. Circular tube + Disk-and-doughnut baffle
4. Square tube + Disk-and-doughnut baffle

Boundary conditions assumed steady-state turbulent flow, no-slip wall condition, and constant fluid properties. Mesh independence was verified to ensure convergence with <3% variation in outlet temperatures.

D. Effectiveness Calculation

Effectiveness (ε) was determined using:

$$\varepsilon = \frac{Q_{\text{actual}}}{Q_{\max}}$$

Where:

$$Q_{\text{actual}} = C_{\min} \cdot (T_{c,out} - T_{c,in})$$

$$Q_{\max} = C_{\min} \cdot (T_{h,in} - T_{c,in})$$

Assuming equal heat capacity rates (Cmin = Cmax), ε reduces to:

$$\varepsilon = \frac{T_{c,out} - T_{c,in}}{T_{h,in} - T_{c,in}}$$

RESULTS AND DISCUSSION

E. Simulation Results

Table 2. Outlet Temperature & Effectiveness Comparison

Configuration	**Shell-Side Outlet (K)**	**Tube-Side Outlet (K)**	**Effectiveness (ε)**
Circular tube + Standard segmental	335.78	319.26	0.824
Square tube + Standard segmental	338.32	317.33	0.783
Circular tube + Disk-and-doughnut	341.95	314.09	0.759
Square tube + Disk-and-doughnut	341.45	314.62	0.752

Figure 2. Circular Tube with Standard Baffle flow Simulation

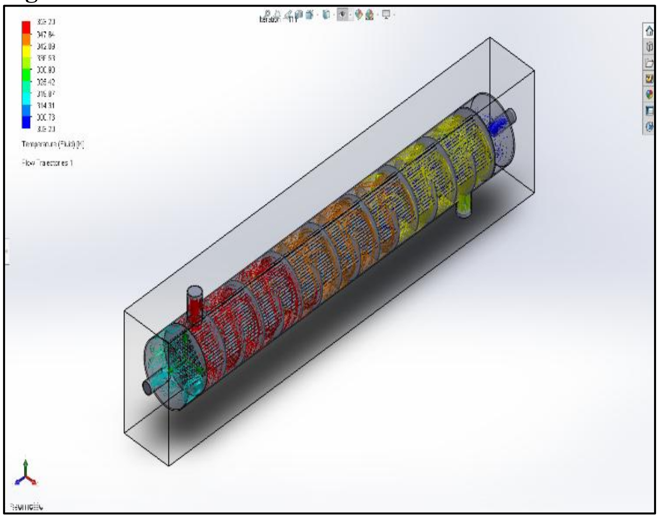


Figure 3. Square Tube with Standard Baffle Flow Simulation

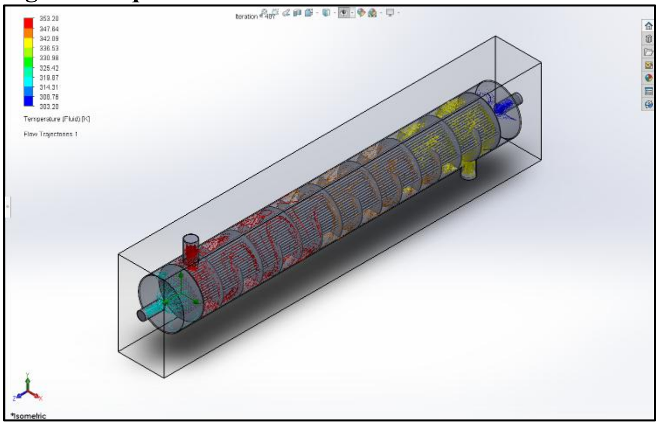


Figure 4. Circular Tube with Disk & Doughnut Baffle Flow Simulation

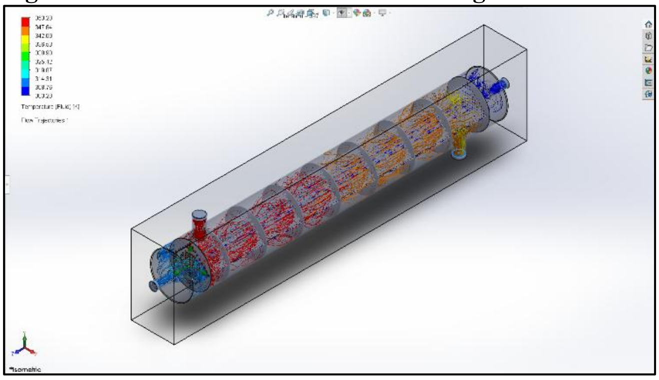
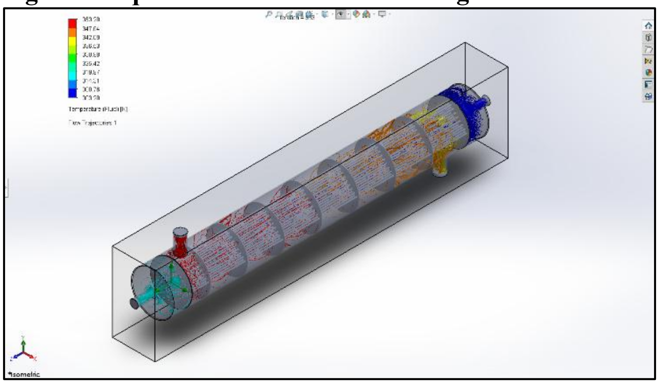


Figure 5. Square Tube with Disk & Doughnut Baffle Flow Simulation



F. Analysis

- Circular + Standard segmental: Produced the highest effectiveness (0.824), indicating superior tube-side heat transfer.
- Square + Standard segmental: Slightly lower effectiveness (0.783), suggesting reduced turbulence compared to circular tubes.
- Circular + Disk-and-doughnut: Balanced shell-side energy recovery but at reduced cooling effectiveness (0.759).
- Square + Disk-and-doughnut: Lowest performance (0.752), indicating inefficiencies when combining non-circular tubes with flow-distributing baffles.

These results highlight the trade-off between cooling effectiveness and shell-side heat recovery depending on geometry and baffle type.

CONCLUSION

The comparative CFD analysis clearly shows that the thermal performance of shell-and-tube heat exchangers is strongly influenced by the choice of tube geometry and baffle configuration. Among the tested models, circular tubes paired with segmental baffles delivered the most effective cooling on the tube side, whereas the square tube with the disk-and-doughnut arrangement exhibited the lowest performance. The calculated effectiveness, ranging from 0.752 to 0.824, underscores the importance of optimizing both parameters to achieve higher efficiency. For future studies, extending the investigation to include pressure drop behavior, fouling tendencies over time, and experimental trials would provide a more comprehensive validation of the numerical results.

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