Material Selection for Shell and Tube Heat Exchanger Using Computational Fluid Dynamics Method

Sunil Shinde[1], Laxmikant Mangate[1], Rudra Kochari[1], Gaurav Khochare[1], Sidhant Kokani[1]

Department of Mechanical Engineering[1],
Vishwakarma Institute of Technology, Pune, 411037, Maharashtra, India

Abstract *- The Shell and Tube Heat Exchanger (STHE) is a critical component in industrial applications, designed to facilitate heat exchange between two fluids. Typically assembled from a bundle of round tubes within a cylindrical shell, the STHE's performance is influenced by material choice and structural design. This study investigates the impact of different materials (aluminium, steel, and copper) and baffle configurations five baffles on heat transfer efficiency. Using Computational Fluid Dynamics (CFD) simulations in ANSYS FLUENT, temperature distribution, heat transfer rate, and pressure drop were analysed. Results demonstrate that copper, combined with five baffles, achieved the highest heat transfer rate, optimal heat transfer coefficient, and minimized pressure drop, establishing it as the most efficient configuration for STHE applications.*

Keywords *- Shell and Tube Heat Exchanger (STHE), Heat transfer efficiency, Computational Fluid Dynamics (CFD), Temperature distribution, Pressure drop, Baffle configuration*

I.INTRODUCTION

Heat transfer is a critical phase within mechanical systems, serving as a fundamental process in energy management across various industrial applications. As energy demand continues to rise globally, the need for efficient heat transfer systems has become increasingly vital. Among the numerous methods available, the shell and tube heat exchanger (STHE) are particularly prominent in industrial settings, where it facilitates the transfer of thermal energy between two fluids. [1]

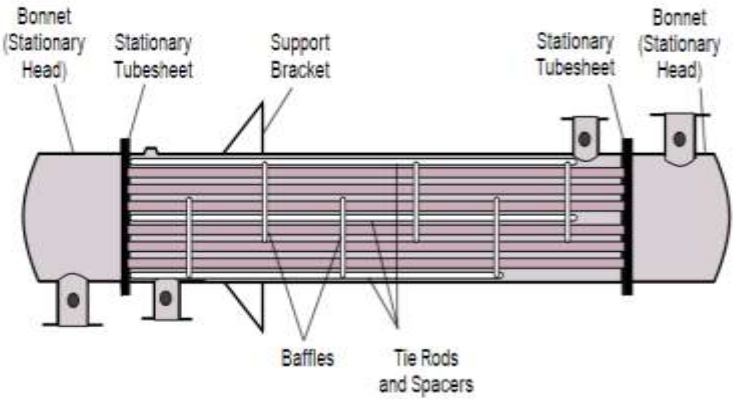


Figure 1: shell and tube heat exchangers (Mukherjee, 1998) [2]

An STHE consists of a cylindrical shell housing an internal tube bundle. During operation, a fluid flows through the shell, coming into contact with the tubes' surfaces, thereby enabling heat exchange between the fluids within and outside the tubes. This design promotes effective thermal energy transfer, essential for numerous industrial processes. However, to ensure sustained performance and operational longevity, selecting high-quality materials for the STHE is crucial. The choice of material directly influences the system's durability, resistance to corrosion, and thermal efficiency, all of which affect production rates and equipment reliability. Consequently, engineers must carefully evaluate material properties and maintenance requirements when designing and operating STHE systems to prevent potential failures and optimize performance.[1]

II.RESEARCH METHODS

RESEARCH STEP

In this study, there were three steps of simulation using Computational Fluid Dynamics (CFD), which were [2]:

1**. Pre-processing** - The first step was to make a model in CAD (Computer Aided Design), create the right mesh, and subsequently apply the limits and the properties of the fluid.

2**. Problem Solving** - Problem solving was a step for using Solvers (Program for finding a solution) of CFD to calculate conditions when the pre-processing was being carried out.

3. **Continued process** - Continued process was the last step in CFD analysis. This stage was the organization and interpretation of data derived from CFD simulation, which were in the forms of image, curve, animation, etc.

COMPUTATIONAL MODEL

The calculation domain as a whole was constricted by the inside of a shell and any other objects located inside the tube within the domain. The inlet and outlet domain were connected to the same tube.

To simplify the numerical simulation, the following assumptions were made [3]:

- Fluids on the shell side has a property of constant thermal;
- Convection occurred by nature due to density variety of the fluid can be ignored;
- Heat exchange is well-isolated, therefore heat loss to the surroundings is completely ignored;
- Leak in flows between tube and baffle, meanwhile leak between baffle and shell is ignored;
- No change in temperature on the wall of the tube at shell side and baffle side;
- Flow of fluids and heat exchange process is a turbulent flow in a steady state.

GEOMETRY AND MESH

Specifications of STHE:

- Type of STHE is the straight type
- Diameter inside shell is Φ 90mm with length of 600mm
- Total number of tubes are 7 (seven) pieces, with the layout of rotated triangular and tube pitch of 30mm
- Dimension of outside diameter is Φ 20mm
- Material of shell and tube is made of steel, aluminium and copper [4]
- Baffle cut dimension is 22%
- Fluids in Shell is cold water and inside tube is warm water

- The baffles are 5 pieces (NP5).

Figure 3 CAD of Shell

Figure 2 Shell Side view

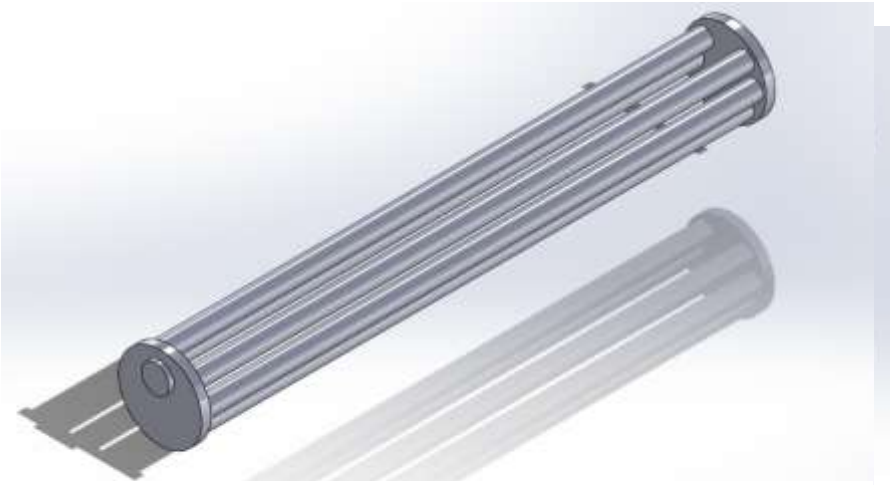


Figure 4 CAD of Tubes

Figure 5 Design of Shell and tube heat exchanger

DISCRETIZE MODEL

Three-dimension model was discretized on CFD by using accurate hexahedral mesh element and involving some calculations. A good control on hexahedral mesh near the surface would lead to high accurate capture of gradient layer boundary. Heat exchanger that has been discretised in terms of solid and fluid domain will have a better control above node numbers. Fluid mesh is better made with solid mesh to simulate the combination of heat transfer. The result of the model that has been discretised is up to the required standard, which later will be exported to ANSYS.

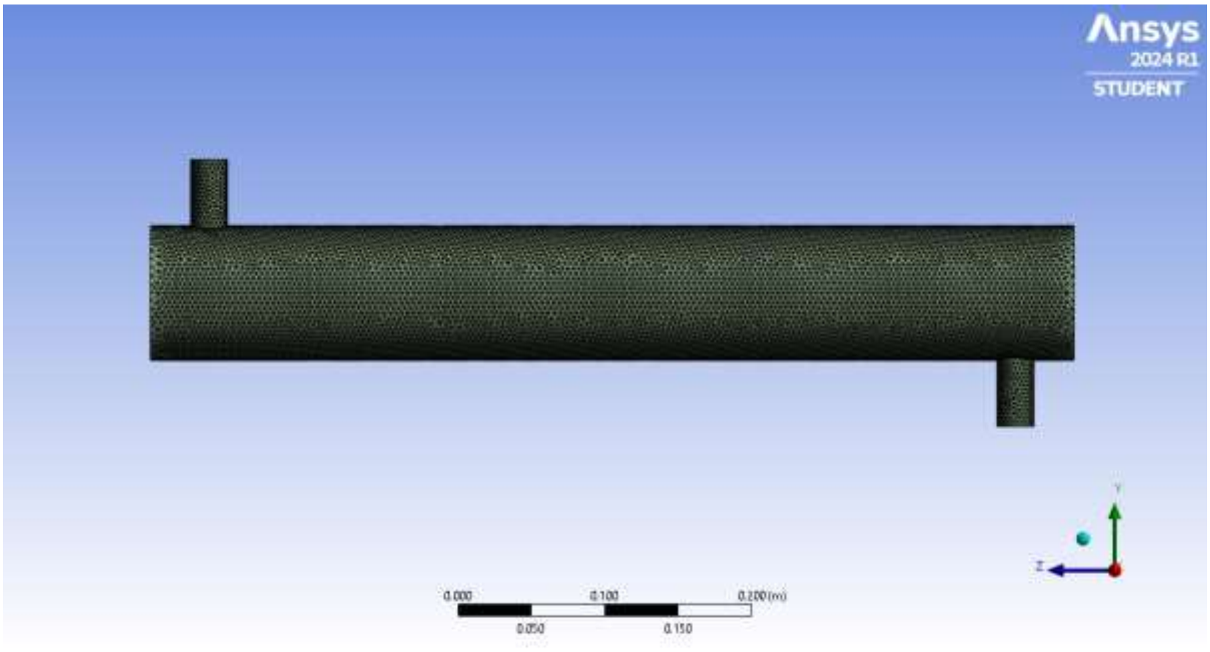


Figure 6 Meshing of STHE

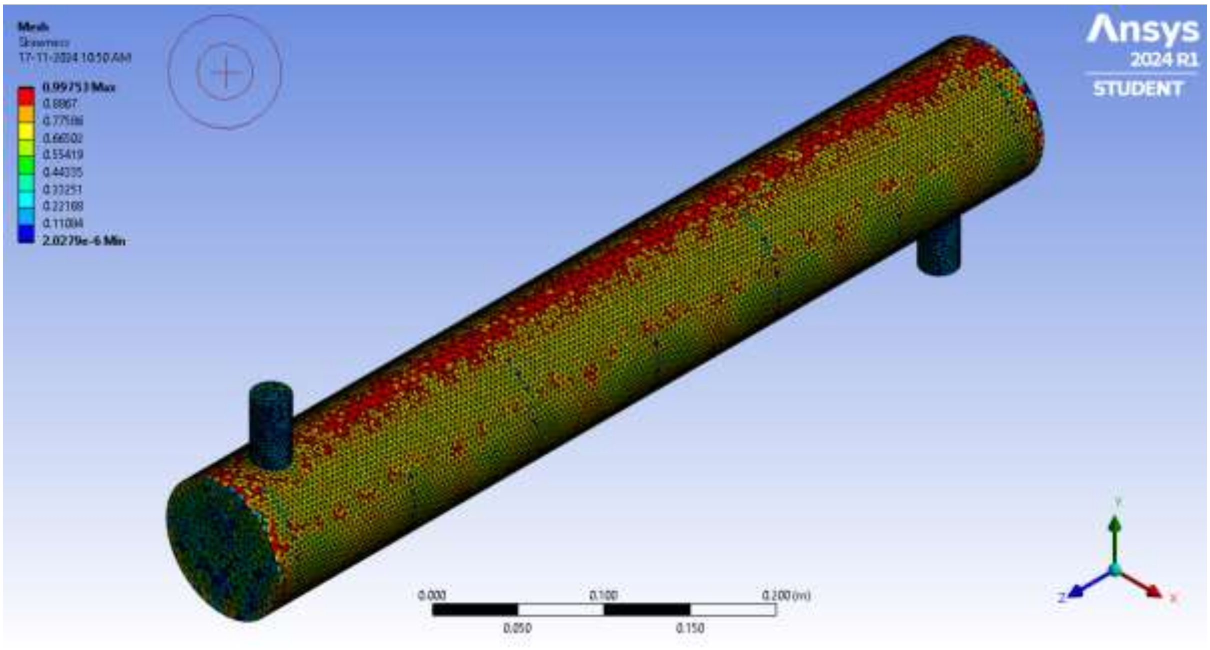


Figure 7 skewness of meshing

MESHING

At first mesh, a large mesh size was created containing of mixed cells (tetra cell and hexahedral cell) with the shape of triangle and rectangle. This method was acquired through the use of structured cell (hexahedral) as much as possible through automatic method that is available on ANSYS meshing client. It was intended to reduce the amount of numerical diffusion as much as possible with an exceptional setup of mesh, most importantly near the wall area in shell. Afterwards, for independent mesh model, a fine mesh was created for the edges and the gradient area that had high temperature and pressure, The produced model was transferred to ANSYS workbench. Furthermore, physic preference of CFD and solver preference of fluent were chosen.

SOLUTION SET-UP

Simulation was done using ANSYS FLUENT software. In the simulation, the preference of type pressure was based, velocity formulation was absolute, and time was transient at the solver part. In the calculation phase, the model with Energy - on, viscous, standard k - ε, standard wall Fn, was preferred.

SOLUTION INITIALIZATION

Solution method used the pressure of velocity coupling with SIMPLE scheme. In Spatial discretization, the preferences were the gradient of least squares cell based, pressure of second order, momentum of second order upwind, turbulent kinetic energy of second order upwind, and turbulent dissipation rate of first order upwind. In the solution control, momentum of 0.7, turbulent kinetic energy of 0.8, turbulent dissipation rate of 0.8, turbulent viscosity of 1 and energy of 1 were opted [5].

III.RESULTS AND DISCUSSION

1) Temperature Distribution over **Aluminium** material Shell and Tube Heat exchangers

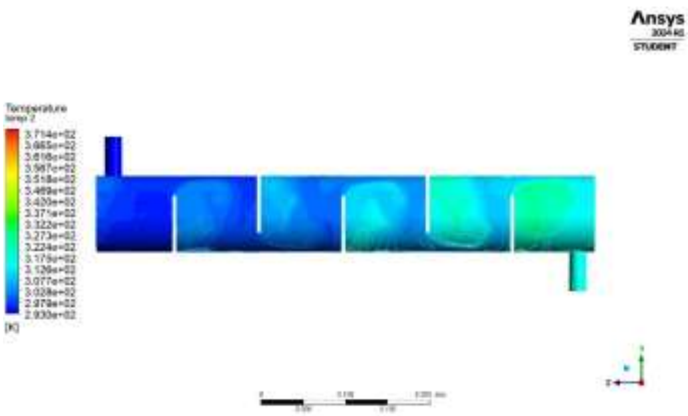


Figure 9 temperature distribution over shell

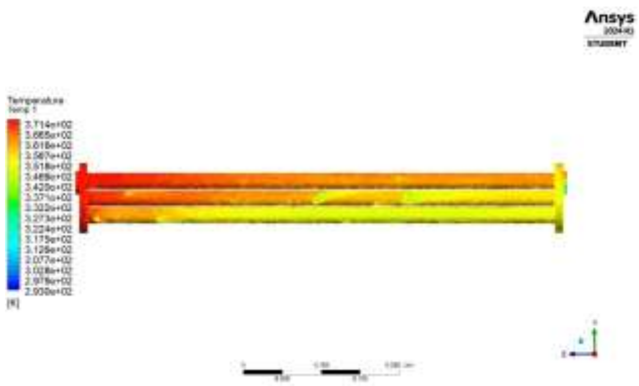


Figure 8 temperature distribution over tube

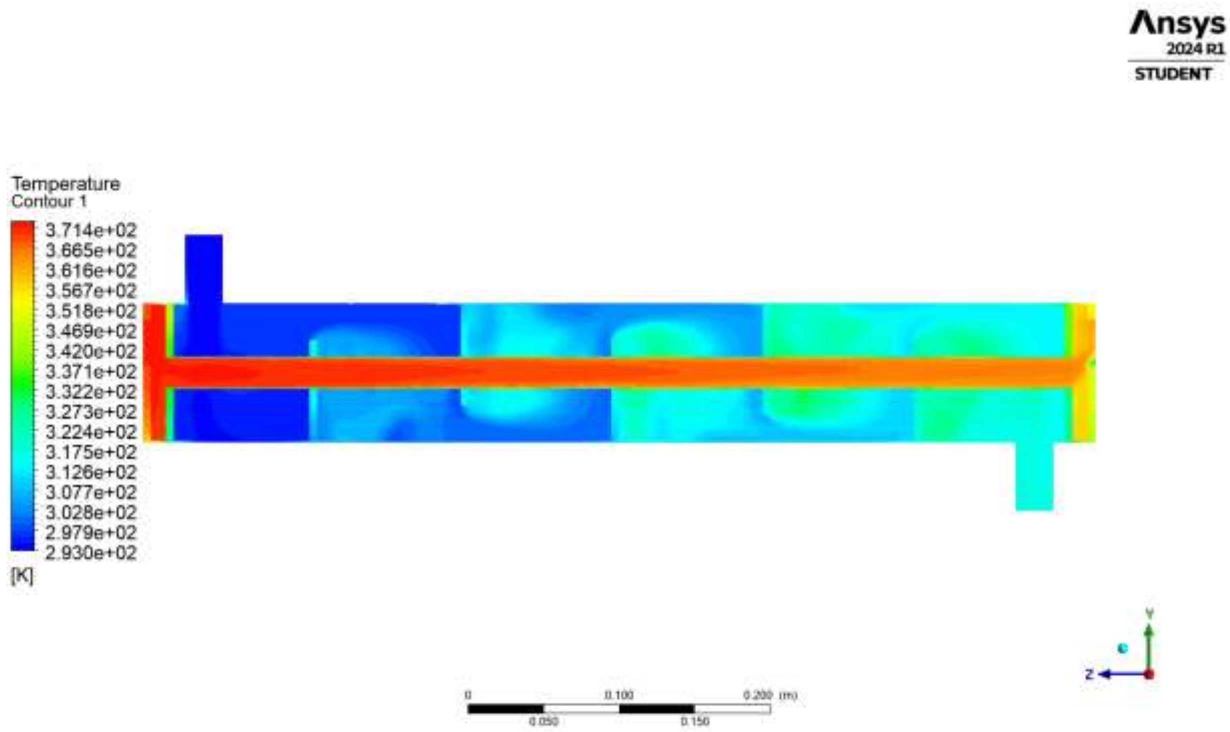


Figure 10 temperature distribution over plane

2) Temperature Distribution over **Copper** material Shell and Tube Heat exchangers

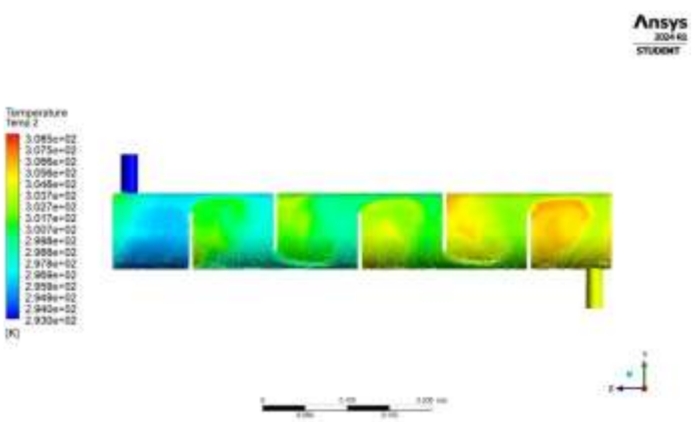


Figure 11 temperature Contour over shell

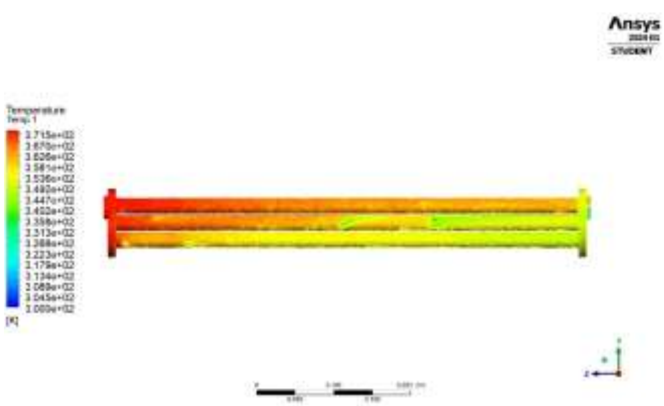


Figure 12 temperature contour over tubes

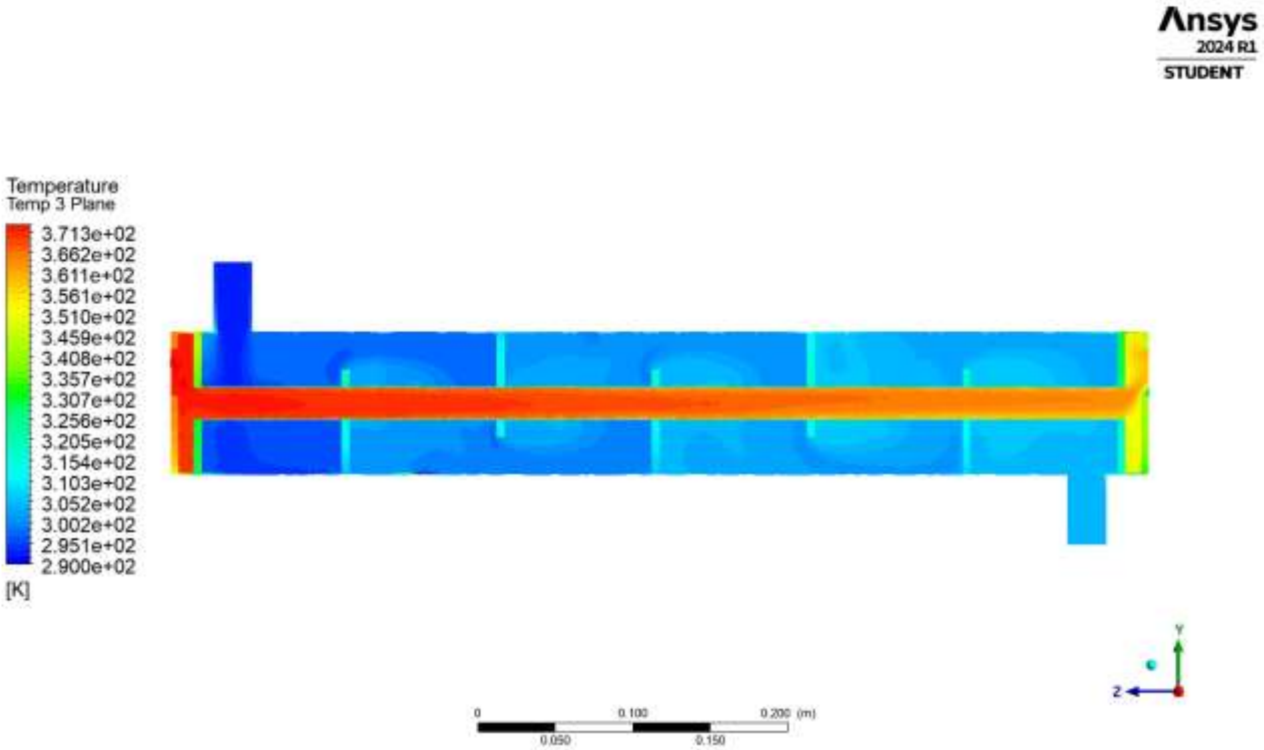


Figure 13 Temperature distribution over Plane

3) Temperature Distribution over **Steel** material Shell and Tube Heat exchanger

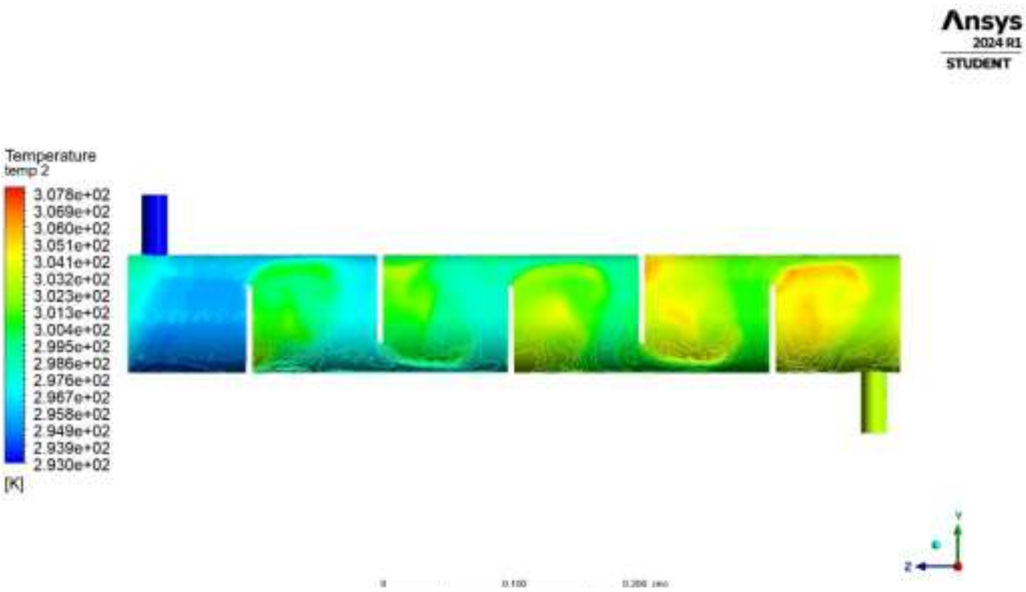
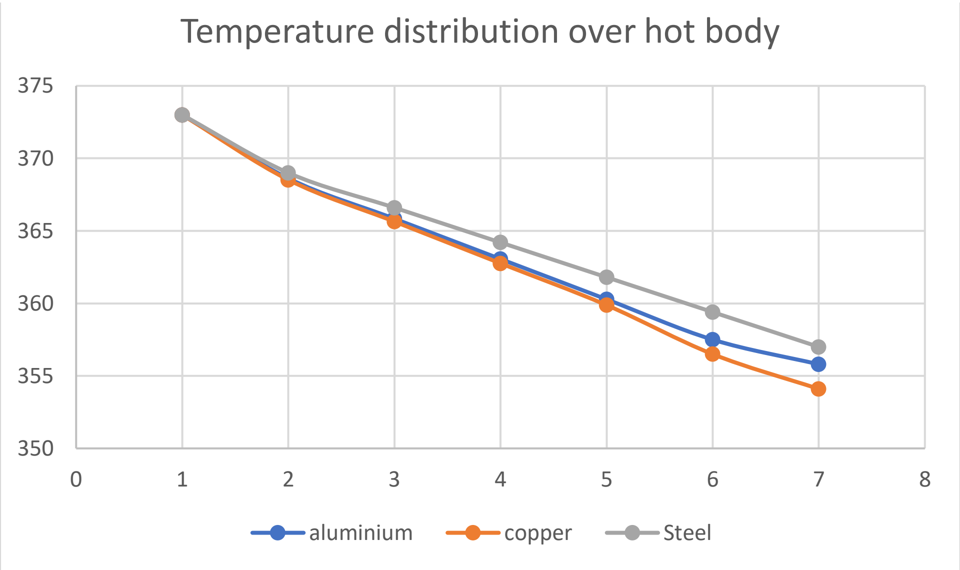


Figure 14 temperature Contour over shell and tube heat exchanger

Table 1 Properties of different materials

Property	Aluminium	Copper	Steel
Thermal Conductivity (W/m·K)	205	385	50
Density (kg/m³)	2700	8960	7850
Specific Heat Capacity (J/kg·K)	900	385	470
Corrosion Resistance	High (oxide layer protection)	Moderate (requires coatings)	High (depending on grade)
Cost	Low	Moderate	Moderate
Mechanical Strength	Moderate	Moderate	high
Weight	Lightweight	Heavy	Heavy
Ease of Fabrication	Easy	Moderate	Difficult

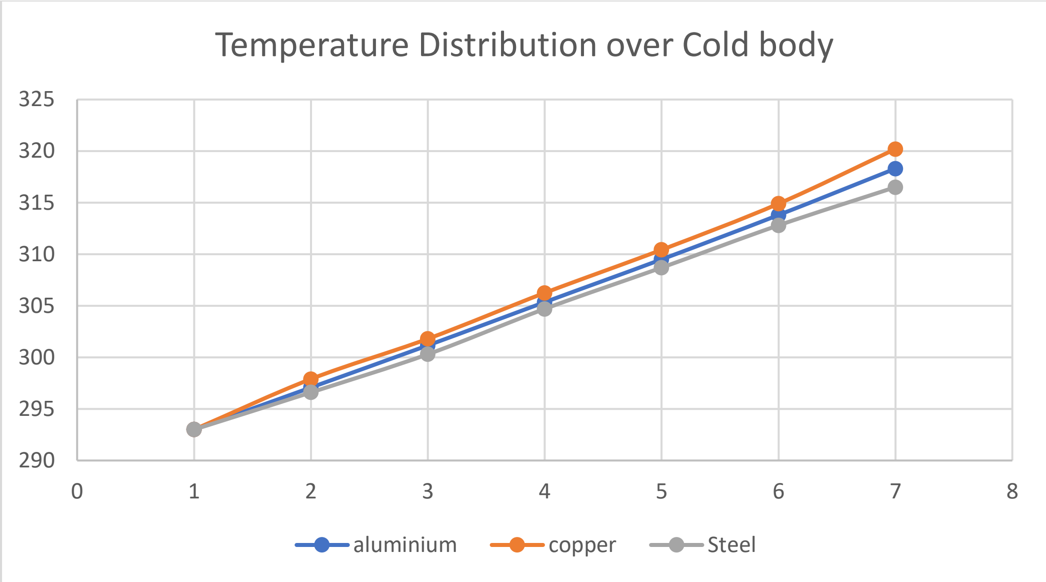
Table 2 temperature distribution over hot body



The **hot fluid's temperature decreases steadily** along the length of the shell for all materials, influenced by their thermal conductivity and heat transfer performance.
The **starting temperature** for all three materials is 373K, but the **ending temperatures differ**:

- **Copper**: 354.0 K (largest temperature drop, highest heat transfer rate).
- **Aluminium**: 355.8 K (moderate temperature drop, good heat transfer performance).
- **Steel**: 357.0 K (smallest temperature drop, lowest heat transfer efficiency).

Table 3 temperature distribution over cold body



The **Cold fluid's temperature Increases steadily** along the length of the shell for all materials, influenced by their thermal conductivity and heat transfer performance.
The **starting temperature** for all three materials is 293K, but the **ending temperatures differ**:

- **Copper**: 320.2 K (largest temperature gain, highest heat transfer rate).
- **Aluminium**: 318.3 K (moderate temperature gain, good heat transfer performance).
- **Steel**: 316.5 K (smallest temperature gain, lowest heat transfer efficiency).

Table 4 Hot body temperature distribution

Sr.no.	STHE material	Initial temperature	Final temperature
1	Aluminium	373K	355.8K
2	Copper	373K	354.1K
3	Steel	373K	357K

Table 5 cold body temperature distribution

Sr.no.	STHE material	Initial temperature	Final temperature
1	Aluminium	293K	318.3 K
2	Copper	293K	320.2 K
3	Steel	293K	316.5 K

IV.CONCLUSION

The study compares the thermal performance of a Shell and Tube Heat Exchanger (STHE) using three different materials: Aluminium, Copper, and Steel. Based on the analysis conducted using CFD simulations and analytical methods, the following conclusions are drawn:

Thermal Conductivity Impact:

- Copper demonstrated superior thermal performance due to its high thermal conductivity, which allows efficient heat transfer between the hot and cold fluids.
- Aluminium, with moderate thermal conductivity, showed reasonable performance, making it a cost-effective alternative to copper.
- Steel, with the lowest thermal conductivity, performed least effectively in transferring heat.

Material Suitability:

- Copper is the most suitable material when performance is prioritized over cost and weight.
- Aluminium offers a balanced trade-off between performance, cost, and weight, making it suitable for applications requiring lightweight construction.
- Steel is better suited for environments prioritizing structural strength and corrosion resistance over thermal performance, such as in high-pressure or high-stress systems.

Applications and Recommendations:

- For industrial applications requiring high efficiency and where cost is less restrictive, Copper is recommended.
- For systems where weight and cost considerations are critical, Aluminium is a feasible alternative.
- Steel is recommended for specific use cases involving harsh environmental conditions or mechanical stress, despite its lower thermal performance

Heat Transfer Insights:

The results underscore the importance of selecting a material with high thermal conductivity and considering operating conditions to optimize the heat exchanger's performance. Material choice directly impacts the efficiency, cost, and longevity of the STHE. This project highlights the trade-offs involved in material selection for STHEs and provides a framework for future research to optimize performance and cost-effectiveness based on specific application needs.

V.REFERENCES

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