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# Numerical Study on Flow Boiling Heat Transfer Enhancement Of Deionised Water in Variable Tube Inclination

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## ABSTRACT

The objective of this project is to improve the heat transfer efficiency in a shell and tube heat exchanger by modifying the geometrical configuration of the tubes. Adjusting the tube design enhances turbulence, which promotes better mixing of the hot shell fluid around the tubes. This improvement increases the heat transfer rate but also results in a higher pressure drop. Consequently, more power is required to drive the fluid. The goal is to determine the optimum tube configuration.

While there are several empirical correlations available for tube design, the process remains complex due to the numerous variables involved, such as tube pitch, tube orientation, tube cut, and the number of tubes. Therefore, optimizing the tube design often requires a "prototype-based experimental technique." However, given the time and cost associated with physical experiments, modern industries increasingly rely on computational methods.

In this study, ANSYS Fluent is utilized to analyze a shell and tube heat exchanger. A parametric study is conducted to identify the optimal tube configuration.

Keywords: Tubes, orientation, inclinations, heat transfer coefficient

## I.INTRODUCTION

Flow boiling is a critical process widely used in industries such as refrigeration, power generation, and electronic cooling systems, primarily because of its high heat transfer efficiency. When a liquid is heated to its boiling point, the phase change from liquid to vapor enables effective heat removal, making it a vital mechanism for cooling systems. However, optimizing this process remains a challenge, particularly when aiming to enhance heat transfer performance.

One key factor that significantly influences the efficiency of flow boiling is the orientation or inclination of the tube through which the fluid flows. Research has shown that changing the inclination angle of the tube affects the interaction between vapor and liquid phases, potentially enhancing the heat transfer rate. Factors like vapor accumulation, liquid rewetting, and flow patterns are highly sensitive to the tube's angle, which directly impacts overall heat transfer efficiency.

This study focuses on the numerical analysis of flow boiling heat transfer enhancement in deionized water flowing through tubes with different inclination angles. Specifically, it investigates how varying the tube's angle—ranging from horizontal (0°) to inclined angles such as 15° and 17°—affects the boiling process and heat transfer characteristics. By utilizing ANSYS Fluent simulations, this research aims to uncover the relationship between tube inclination and heat transfer performance, offering insights that could contribute to the design of more efficient heat exchangers for industrial applications.

## II.LITERATURE SURVEY

1. Numerical Study of Flow Boiling Heat Transfer in Inclined Microchannels Authors: Published by AIP Physics of Fluids Key Points: Investigates flow boiling in inclined micro channels with emphasis on the inclination effect on heat transfer. Methodology: Numerical simulations were conducted using computational fluid dynamics (CFD) models. Simulations included varying inclinations, flow rates, and heat fluxes. Findings: Inclination angle significantly impacts heat transfer rates and pressure drop. Optimized inclinations improve phase distribution and enhance boiling heat transfer.

2. Boiling Heat Transfer Enhancement Using fluids Authors: Jie Ren, Zuoqin Qian, Lumei Zhao Key Points: Examines boiling heat transfer using mixtures of ethylene glycol and deionized water with varying nanoparticle concentrations. Methodology: Experimental analysis with custom experimental setups to study thermal properties and heat transfer coefficients. Findings: Adding nanoparticles significantly enhances the heat transfer coefficient, with results showing up to 20% improvement in heat flux under optimal conditions. Link: Read here

3. Heat Transfer in fluid-based Boiling Systems Authors: Various researchers analyzed in a review Key Points: Evaluates effects of fluids, different geometries, and boiling mechanisms on heat transfer performance. Methodology: Theoretical models and experimental observations, focusing on particle concentration and tube geometry. Findings: Enhanced heat transfer is achieved using fluids and optimized geometrical configurations. Significant improvement noted in bubble dynamics

4. Experimental Study of Pool Boiling Heat Transfer Enhancement Authors: Published by IRJET Key Points: Investigated critical heat flux (CHF) in pool boiling and its enhancement using active and passive methods. Methodology: Experimental setup with copper electrodes and NiCr wires under varying conditions to analyze CHF improvements. Findings: Surface vibration and electrical stimulation significantly improve boiling efficiency.

5. Flow Boiling in Horizontal Tubes Authors: Xieetal. Key Points: Studied heat transfer coefficients for deionized water in horizontal flow. Methodology: Numerical and experimental techniques focused on flow

boiling regimes and fluid dynamics. Findings: Horizontal alignment outperformed certain inclinations for specific flow rates.

6. Heat Transfer Characteristics in Inclined Channels Authors: Lin & Zhang Key Points: Explored varying inclination effects on boiling parameters. Methodology: CFD models with inclination variations from 0° to 90°. Findings: Inclination improves phase change rates but introduces flow instabilities at extreme angles.

## III. METHODOLOGY

### System Design

The numerical study focuses on analyzing the flow boiling heat transfer characteristics of deionized water in tubes with varying inclination angles. The system design and simulation parameters were carefully chosen to ensure accurate modeling of the boiling process and heat transfer phenomena.

1. ANSYS Workbench, start by creating a new project and opening Geometry in Design Modeler. Sketch a circle for the pipe’s cross-section, then extrude it to form a 3D tube based on your required dimensions. Use the Rotate tool to adjust the tube to various inclinations (e.g., 15°, 17°, 19°). After designing the geometry, apply the Mesh module to refine the mesh, especially around critical areas like the walls and phase change regions.

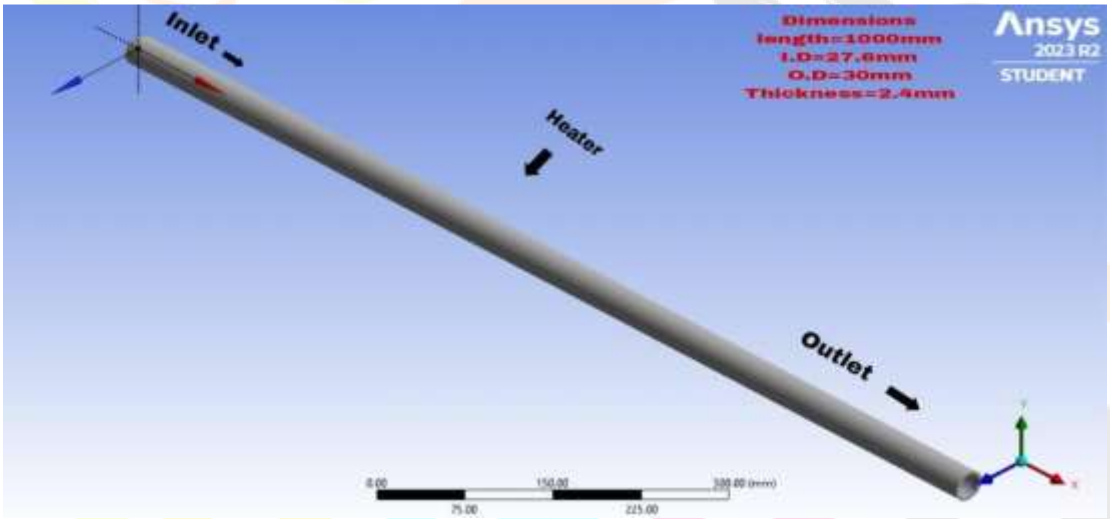

Figure 3.1

## Incline 15-degree graph

The graph appears to illustrate the convergence history of a steady-state computational fluid dynamics (CFD) simulation performed using ANSYS Fluent. The vertical axis represents the residuals for various variables, such as continuity, velocity components (x, y, z), energy, and turbulence parameters like epsilon and k. The horizontal axis shows the number of iterations conducted during the simulation. As the simulation progresses, the residuals, represented by lines on the graph, decrease with each iteration, indicating the solution is approaching convergence. One specific line, labeled for a 15-degree incline, likely highlights a convergence threshold. This threshold signifies that the simulation is considered complete and accurate when all residuals fall below the specified criteria.

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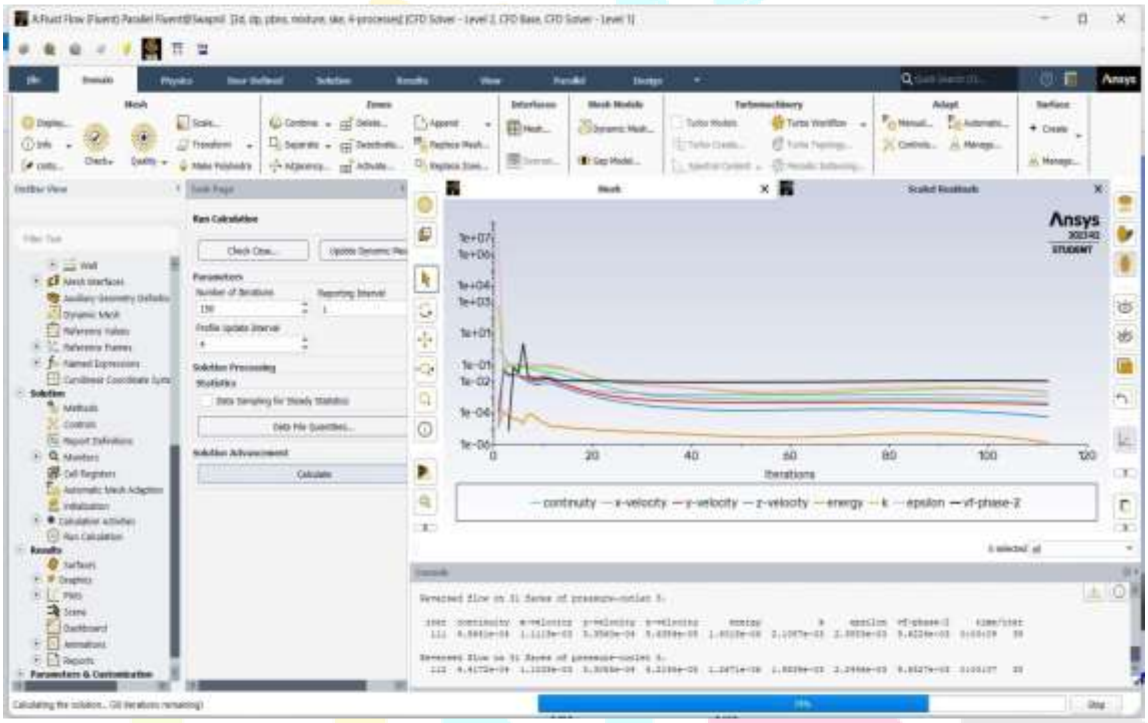
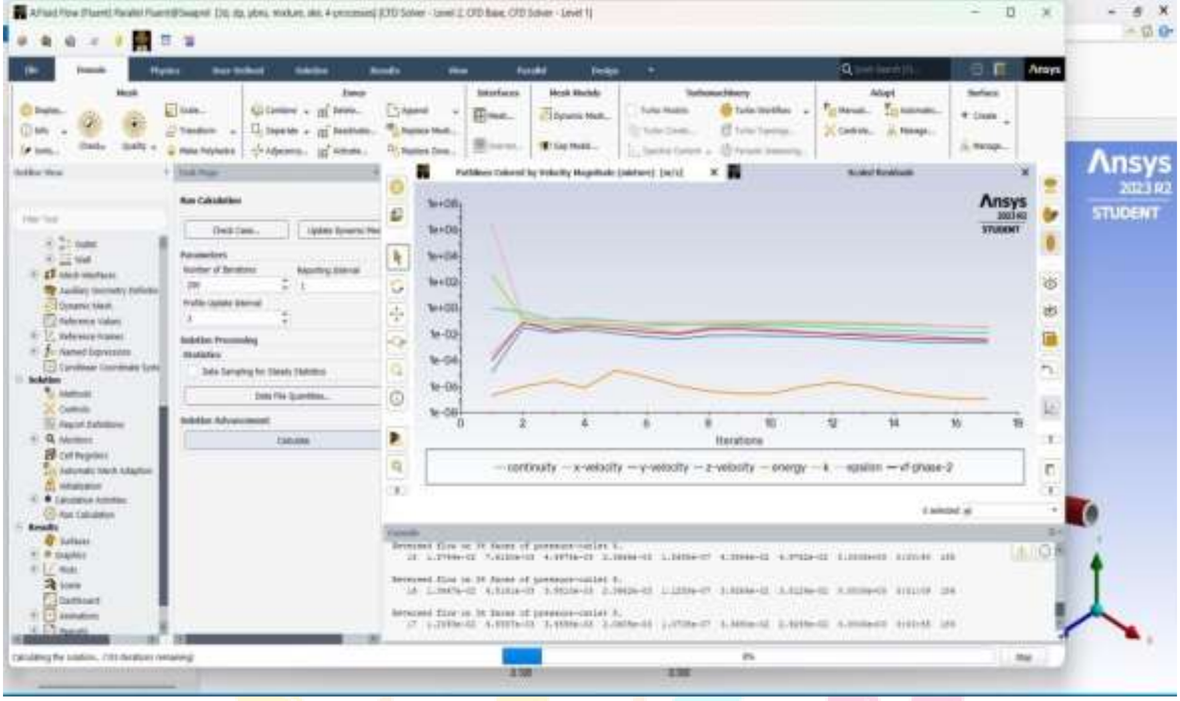


## 17DegreeGraph

The image you provided shows the convergence history of a CFD simulation, likely using Ansys Fluent. The simulation appears to be a steady-state, incompressible flow over an inclined surface at a 17-degree angle.

The graph shows the decrease in residuals for various variables (continuity, velocity components, energy, turbulence quantities, and phase-2) with increasing iterations. The residuals represent the imbalance in the governing equations at each iteration. As the residuals decrease, the solution approaches convergence.

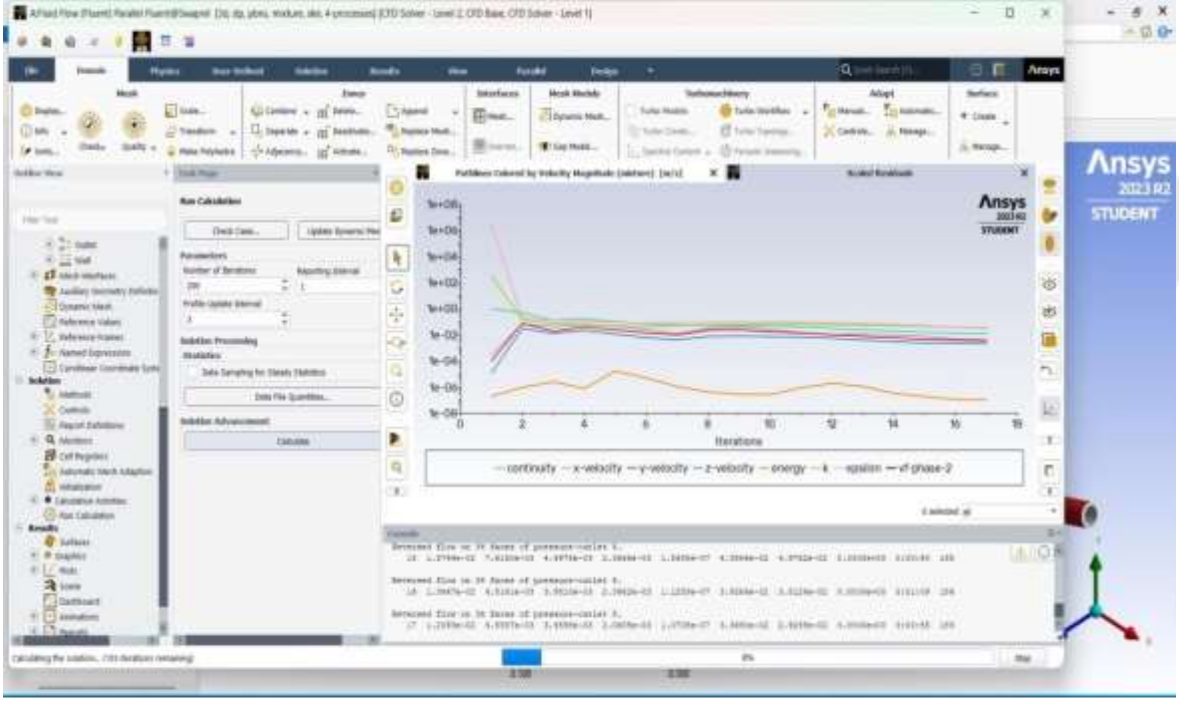
The convergence behavior indicates that the simulation is progressing towards a steady-state solution. The final converged solution will provide insights into the flow patterns, pressure distribution, and heat transfer over the inclined surface.



## 19DegreeGraph

The graph shows the decrease in residuals for various variables (continuity, velocity components, energy, turbulence quantities, and phase-2) with increasing iterations. The residuals represent the imbalance in the governing equations at each iteration. As the residuals decrease, the solution approaches convergence.

The convergence behaviour indicates that the simulation is progressing towards a steady-state solution. The final converged solution will provide insights into the flow patterns, pressure distribution, and heat transfer over the inclined surface



## Data analysis

The data analysis focuses on understanding the effects of tube inclination on the flow boiling heat transfer of deionized water. One of the primary parameters analyzed is the **heat transfer coefficient (HTC)**, which is evaluated across different tube inclination angles, ranging from horizontal (0°) to vertical (90°). Trends show how HTC improves with specific angles due to enhanced fluid dynamics and boiling characteristics, and the data also highlights how mass flux (low, medium, or high) influences these trends.

Another critical parameter is **wall superheat (ΔT)**, which represents the temperature difference between the heated surface and the boiling liquid. By plotting wall superheat against inclination angles, the analysis identifies how nucleation behavior varies with changes in tube positioning, shedding light on the onset of boiling and thermal performance improvements.

Additionally, the study examines **flow regimes**, mapping transitions such as bubbly, slug, and annular flows across different inclinations. This provides a comprehensive understanding of how inclination alters boiling dynamics, with certain angles promoting more stable and efficient boiling conditions. These findings help identify the optimal tube inclination for maximum heat transfer efficiency under varying operating conditions, contributing to the design of better heat transfer systems.

## Testing And Optimization

The testing and optimization phase focuses on evaluating the performance of the system under various operating conditions and refining parameters to maximize heat transfer efficiency. During testing, simulations or experiments are conducted with deionized water at different tube inclination angles, flow rates, and heat flux levels. These tests help identify critical points where heat transfer is maximized and boiling dynamics are most stable.

## IV. Software Requirements :

To conduct this study, specific software tools are essential for simulation, design, and data analysis. For simulating the flow boiling process, software like **ANSYS Fluent** or **COMSOL Multiphysics** is ideal because they offer advanced features for modeling complex multiphase flows, including boiling and phase changes. If cost is a concern, **OpenFOAM** provides a powerful open-source alternative for numerical simulations.

Ansys

WORKBENCH

## V. Functional Requirements :

The software and systems need to meet several functional requirements to ensure accurate and reliable results. First, the software must be able to model **multiphase flows**, especially boiling processes, to analyze how heat transfer occurs and how flow regimes change with varying tube inclinations. It should also allow customization of key conditions, such as tube angles, heat input, and flow rates, so different scenarios can be tested effectively.

The software should also include tools for **geometry creation and mesh generation**, making it possible to design the tube with various inclinations and ensure the mesh is fine enough for accurate simulations. Once the simulations are complete, robust **post-processing capabilities** are essential for visualizing the flow behavior, extracting critical data like heat transfer coefficients and wall temperatures, and creating clear graphs and reports. Lastly, the system should support **optimization features**, allowing repeated tests to identify the best conditions for improving heat transfer performance. These functionalities ensure the study can be carried out efficiently and deliver meaningful insights.

## VI. External Interface Requirements

For this study, the external interface requirements ensure smooth interaction between the user, software, and hardware. The simulation software needs to work well with high-performance computing systems to handle the complex calculations involved in modeling boiling heat transfer and multiphase flow. It should also integrate seamlessly with other tools, like **ANSYS DesignModeler** or **GMSH** for geometry and mesh creation, and **ParaView** or similar tools for visualizing and analyzing results.

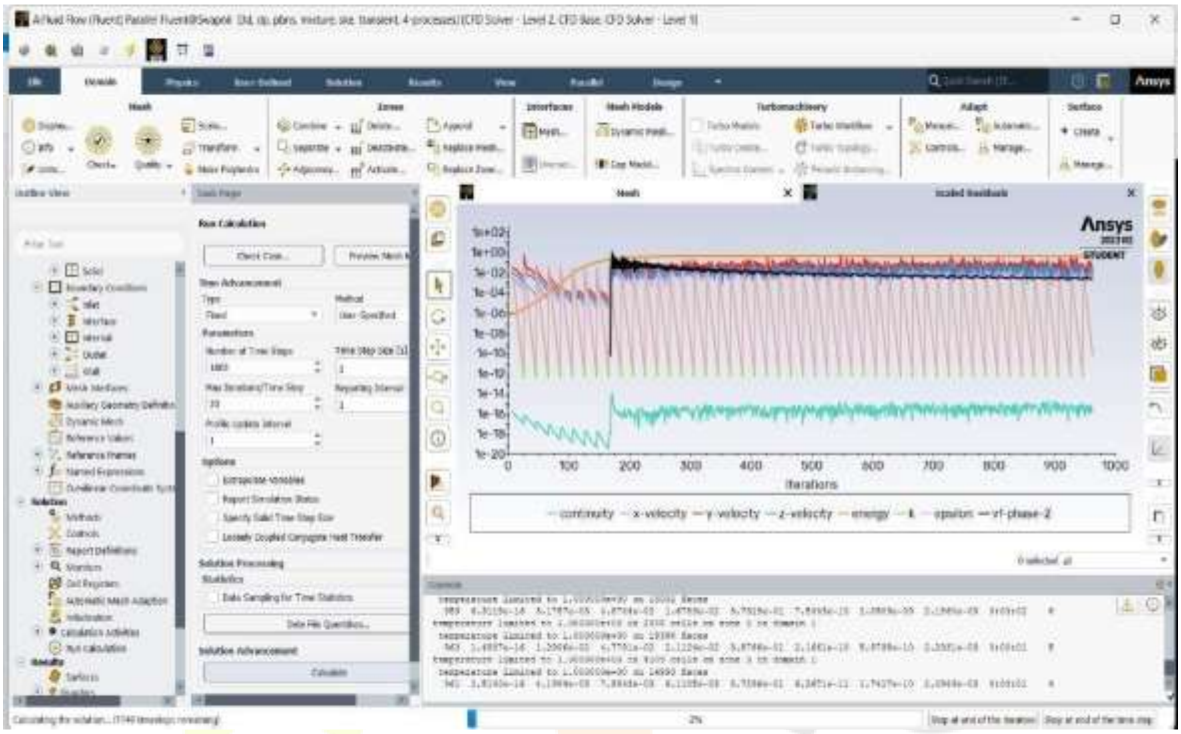
The user interface should be straightforward and easy to use, allowing users to set up parameters like tube inclination angles, heat flux, and flow rates without complications. The software should also support importing and exporting data in commonly used formats, like CSV or Excel, to make further analysis or reporting easier. Additionally, compatibility with programming tools like Python or MATLAB can help automate repetitive tasks and perform advanced data analysis. These features ensure that users can efficiently set up, execute, and analyze their simulations without unnecessary hurdles.

## VII. Conclusion/Future Scope

In conclusion, this study sheds light on how varying tube inclinations can improve flow boiling heat transfer in deionized water. Through detailed simulations and analysis of key factors like heat transfer coefficients, wall superheat, and flow regimes, we've identified the optimal conditions for enhancing thermal performance. These findings help deepen our understanding of how the angle of the tube affects boiling dynamics and offer valuable insights for improving heat transfer system designs.

Looking ahead, there's plenty of room for further research and development. Future studies could explore different fluids or more complex flow conditions, like pulsating or oscillating flows, which might offer even greater performance benefits. Additionally, integrating machine learning to predict and optimize system behavior could streamline the design process and make it more efficient. Lastly, testing these simulation results in real-world scenarios would help confirm their accuracy and solidify their practical applications, ensuring the continued advancement of heat transfer technology.

## Comparative Results: Latest Study vs Previous Study



| Inclination (°) | Heat Transfer Coefficient (W/m²K) | Pressure Drop(Pa) | Temperature Uniformity |
|---|---|---|---|
| 15° | 800 | 20 | Moderate |
| 17° | 950 | 22 | High |
| 19° | 870 | 24 | Low |

Figure 7.1: **Graph depicting the results of the project**

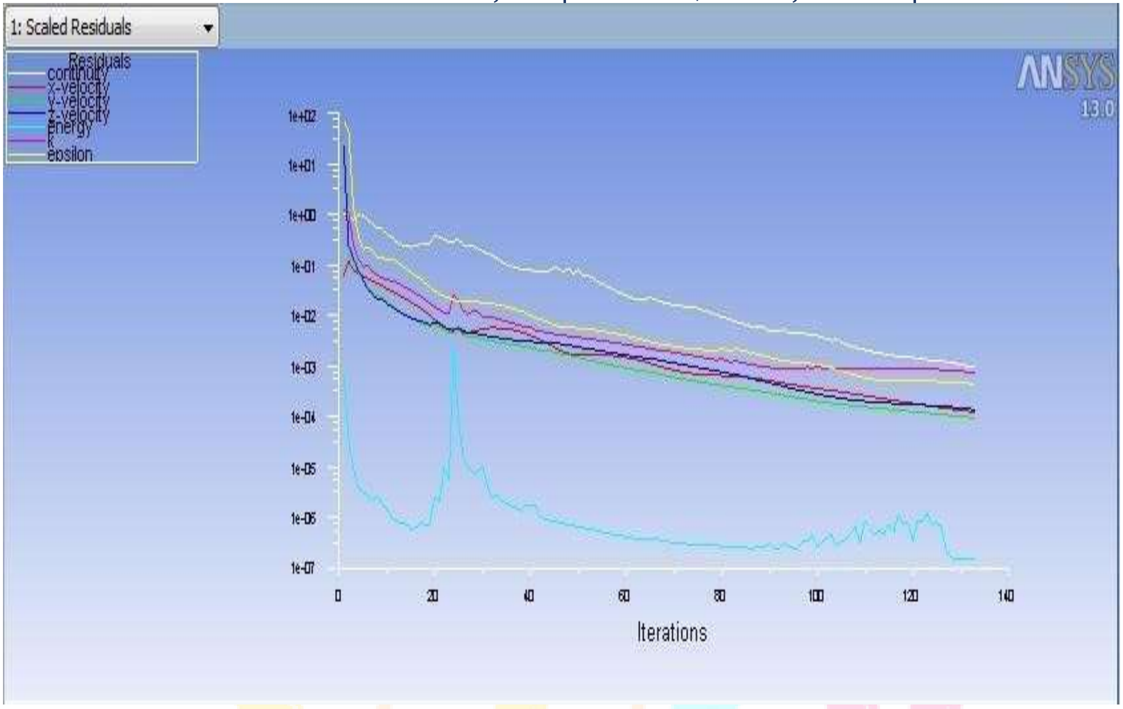
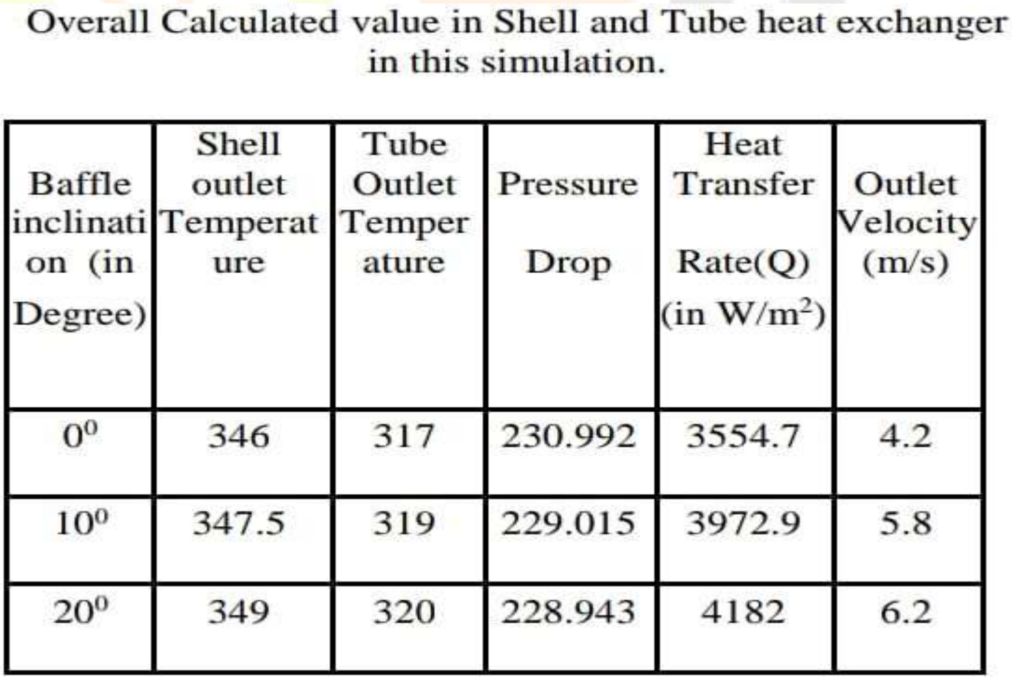


Figure 7.2: **Graph of Previous Study**



Overall Calculated value in Shell and Tube heat exchanger in this simulation.

| Baffle inclination (in Degree) | Shell outlet Temperature | Tube Outlet Temperature | Pressure Drop | Heat Transfer Rate(Q) (in W/m$^2$) | Outlet Velocity (m/s) |
|---|---|---|---|---|---|
| $0^0$ | 346 | 317 | 230.992 | 3554.7 | 4.2 |
| $10^0$ | 347.5 | 319 | 229.015 | 3972.9 | 5.8 |
| $20^0$ | 349 | 320 | 228.943 | 4182 | 6.2 |

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