



Simulation-Based Comparative Study of Heat Transfer in Smooth and Threaded Absorber Pipes in Parabolic Trough Collector

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ABSTRACT

This study investigates the thermal performance of smooth and externally threaded absorber pipes used in parabolic trough collectors (PTCs) under identical operating conditions. The efficiency of PTC systems depends significantly on the heat transfer between the absorber pipe and the working fluid. Conventional smooth pipes possess limited surface area, restricting heat transfer and reducing thermal efficiency. To improve performance, externally threaded pipes are proposed as a passive heat transfer enhancement technique. Three-dimensional models of smooth and threaded absorber pipes were designed and analysed using ANSYS Fluent under identical heat flux and flow conditions. Computational fluid dynamics (CFD) simulations were performed to evaluate heat transfer characteristics, thermal efficiency, and flow behaviour. The results showed that the externally threaded pipe achieved higher average fluid temperatures compared to the smooth pipe under all heat flux conditions. At heat flux values of 1100 W/m², 2000 W/m², and 2500 W/m², the threaded pipe exhibited temperature improvements of approximately 5.3%, 9.2%, and 10.7%, respectively, over the smooth pipe due to the increased surface area provided by the external threads. The study concludes that externally threaded absorber pipes can effectively enhance heat transfer performance and improve the overall thermal efficiency of parabolic trough collector systems.

KEYWORDS

Parabolic Trough Collector (PTC), smooth and externally threaded absorber pipes, Heat Transfer Enhancement, Thermal Efficiency, Computational Fluid Dynamics (CFD), ANSYS Fluent, Heat Flux.



1. INTRODUCTION

The growing demand for sustainable and energy-efficient technologies has led to significant advancements in solar thermal energy systems in recent years. Among the various solar concentrating technologies, Parabolic Trough Collector (PTCs) have gained considerable attention because of their simple design, high thermal efficiency, and ability to produce medium- to high-temperature heat for industrial and power generation applications. The performance of a PTC system mainly depends on the efficiency of heat transfer between the absorber pipe and the working fluid flowing through it. Conventional smooth absorber pipes are widely used in these systems; however, their relatively low surface area limits heat transfer and reduces the overall thermal efficiency of the collector. As a result, enhancing the heat transfer capability of absorber pipes has become an important research focus for improving the performance of solar thermal systems.

To improve the thermal behaviour of absorber pipes, several passive heat transfer enhancement techniques such as fins, inserts and corrugated surfaces have been explored by researchers. Among these approaches, externally threaded pipes provide a simple and economical method for increasing the surface area and improving thermal interaction between the absorber pipe and the working fluid. In this study, the thermal performance of smooth and externally threaded absorber pipes used in PTC systems is analysed under identical operating conditions using Computational Fluid Dynamics (CFD) simulations in ANSYS Fluent. Three-dimensional models of both pipe configurations were developed and evaluated under different heat flux conditions to study heat transfer characteristics, flow behaviour, and thermal efficiency. The findings of this study demonstrate the potential of externally threaded absorber pipes as an effective passive heat transfer enhancement technique for improving the overall thermal performance of parabolic trough collector systems.

2. LITERATURE SURVEY

Numerous studies have been conducted on Parabolic Trough Collector (PTCs), focusing on simulation and analysis techniques used in PTC research. It includes investigations related to absorber tube modelling and the analysis of various components within PTC systems. Hyemin Kim et al. [1] This examines recent advancements in parabolic trough collectors (PTCs), focusing on design innovations (advanced reflectors, selective coatings, novel receiver geometries), optimization via FEA, CFD, and multi-objective algorithms, and automated dual-axis tracking systems to enhance efficiency and reduce thermal losses. It highlights diverse applications in power generation, industrial heating, desalination, and building systems, while discussing economic viability, environmental benefits, current challenges, and future directions in smart materials and advanced manufacturing. Elwekeel et al. [2] A numerical CFD study on the absorber tube of a parabolic-trough collector (PTC) in a direct-steam generation (DISS) plant investigated swirling flow induced by tangential inlets as a passive heat transfer enhancement technique compared to conventional axial flow. Results at high Reynolds numbers showed significant improvements, including ~9.1 K reduction in lower surface temperature, 12.7% higher useful heat gain, 41.7% increase in heat transfer rate, 16.4% lower friction factor, and 10.9% reduction in required absorber surface area, along with developed thermal-performance correlations. Teerapath Limboonruang et al. [3] studies on Parabolic Trough Collector absorber tubes mainly focused on improving heat transfer using finned, grooved, and optimized receiver geometries through experimental and numerical analyses. Limboonruang et al. particularly investigated externally finned absorber tubes by varying fin configurations and experimentally validating their thermal performance, highlighting their potential as a simple and cost-effective heat transfer enhancement technique. Qiliang Wang et al. [4] the reduction of thermal-radiative losses in Parabolic Trough Collector receivers by introducing inner radiation shields and selective coatings in the absorber tube design. They carried out detailed numerical simulations along with experimental validation on two receiver configurations and demonstrated that the proposed inner-shielded designs significantly reduced heat loss and improved collector efficiency at high operating temperatures. Tianxiang Hu et al. [5] In Parabolic Trough Collector systems, researchers reduce heat loss from absorber tubes using coatings, special envelopes, and shape modifications. Wang et al. improved efficiency using evacuated, selectively coated tubes, while Hu et al. showed that reshaping the tube (NS-tube) further reduces losses and improves thermal performance.

3. PROBLEM IDENTIFICATION AND OBJECTIVES



The present work on Parabolic Trough Collector systems focuses on the limitation of heat transfer between the absorber pipe and the working fluid, which significantly affects overall thermal performance. Conventional smooth absorber pipes provide limited surface area, resulting in reduced heat transfer rates and lower collector efficiency. To overcome this issue, externally threaded absorber pipes are considered as a passive heat transfer enhancement technique, as the threaded surface increases the effective heat transfer area without major alterations to the flow conditions. However, limited studies are available that clearly quantify the thermal improvement achieved through threaded absorber pipes under identical operating conditions.

Therefore, the study aims to perform a comparative analysis between smooth and externally threaded absorber pipes under the same operating conditions. The work evaluates the influence of increased surface area on heat transfer rate, thermal efficiency, and flow behaviour within the absorber tube. The objective is to determine whether externally threaded absorber pipes can provide a meaningful improvement in thermal performance compared to conventional smooth pipe configurations in practical PTC applications.

4. ANALYSIS PARAMETERS OF ABSORBER PIPE

4.1. SMOOTH ABSORBER PIPE

The smooth absorber pipe used in the Parabolic Trough Collector system is a cylindrical metallic tube with uniform inner and outer surfaces. It absorbs concentrated solar radiation on the outer surface and transfers heat to the heat transfer fluid (HTF) flowing inside. The smooth pipe was considered as the baseline configuration for comparison. The pipe dimensions are 50 mm outer diameter, 40 mm inner diameter, and 1000 mm length

4.2. EXTERNALLY THREADED ABSORBER PIPE

The externally threaded absorber pipe has the same dimensions as the smooth pipe but includes external threading to increase the effective heat transfer area. A standard metric thread (M52 × 1.5) was designed on the outer surface to enhance thermal performance. The internal surface was maintained smooth to ensure identical flow conditions, allowing thermal variations to occur only due to the external threading configuration.

5. FLOW CONDITIONS AND TURBULENCE ANALYSIS

In the present study, water is used as the heat transfer fluid (HTF) and enters the absorber pipe through a velocity inlet boundary condition in the CFD model. The inlet velocity is maintained at 2.5 m/s, as it significantly influences the internal flow behaviour, convective heat transfer coefficient, and pressure drop within the pipe. The average fluid velocity is determined using the relation:

$$V = \frac{Q}{A} \quad (1) \quad -$$

where Q represents the volumetric flow rate and A denotes the cross-sectional area of the pipe. Using a volumetric flow rate of 0.00491 m³/s and a pipe cross-sectional area of 1.963×10^{-3} m², the inlet velocity is calculated as 2.5 m/s. The internal surface of both the smooth and externally threaded absorber pipes is maintained identical to ensure consistent internal flow conditions, allowing the effect of external threading on thermal performance to be evaluated accurately.

The flow inside both absorber pipe configurations is designed to be turbulent in order to enhance heat transfer between the pipe wall and the working fluid. Turbulent flow improves fluid mixing and increases the convective heat transfer coefficient, which is beneficial for solar thermal applications. The flow regime is determined using the Reynolds number given by:



$$Re = \frac{VD}{\nu} \quad (2) \quad \text{---}$$

where V is the fluid velocity, D is the pipe inner diameter, and ν is the kinematic viscosity of water. For an inner pipe diameter of 0.04 m, inlet velocity of 2.5 m/s, and water kinematic viscosity of $1 \times 10^{-6} \text{m}^2/\text{s}$ at 25 °C, the Reynolds number is calculated as 100000, which is significantly higher than the turbulent flow threshold of 4000. Therefore, turbulent flow is ensured throughout the analysis, enabling effective heat transfer and a reliable comparison between smooth and externally threaded absorber pipes.

6. HEAT FLUX ON THE ABSORBER TUBE

In the Parabolic Trough Collector system, the absorber tube acts as the primary receiver of concentrated solar radiation reflected from the parabolic mirrors. In the CFD simulation, this solar energy is applied as a uniform heat flux on the outer surface of the absorber pipe. The applied heat flux represents the rate of thermal energy transferred per unit surface area and is responsible for heat conduction through the pipe wall and subsequent convection to the working fluid flowing inside the tube. In the present study, heat flux values within the typical operating range of PTC systems were considered to evaluate the thermal behaviour of both smooth and externally threaded absorber pipes.

$$\dot{q}'' = G_{solar} \times C_r \times \eta_{optical} \times \cos(\theta_t) - h_{loss} (T_r - T_a) \quad (3)$$

where G_{solar} is the direct normal irradiance, C_r is the concentration ratio, $\eta_{optical}$ is the optical efficiency, and h_{loss} represents the heat loss coefficient. The concentration ratio is calculated from the collector aperture area and absorber surface area, resulting in a value of 11.46 for the present configuration. Based on different solar irradiance conditions, three heat flux cases of 1122 W/m², 1931 W/m², and 2526 W/m² were applied in the analysis. These conditions enable a comparative evaluation of the thermal performance and heat transfer characteristics of smooth and externally threaded absorber pipes under varying solar loading conditions.

7. SIMULATION MODEL AND MESH GENERATION

After completing the geometric modelling in Creo Parametric, both smooth and externally threaded absorber pipe models were exported and imported into ANSYS Workbench for CFD analysis. An ANSYS Fluent conjugate heat transfer analysis system was selected for the simulation. The imported geometries were opened in DesignModeler, where geometry reconstruction and verification were carried out to ensure that the imported models accurately matched the original CAD designs. Quality checks such as surface stitching, gap identification, edge smoothing, and feature verification were performed to eliminate geometric inconsistencies that could affect the simulation results.

After geometry verification, unnecessary small features and micro-details that did not influence heat transfer behaviour were simplified using geometry repair tools to improve computational efficiency. The cleaned and watertight geometries were then transferred to the ANSYS Meshing module for computational grid generation. Global mesh sizing was applied to maintain a balance between simulation accuracy and computational cost, while local mesh refinement was introduced in critical regions such as the threaded surfaces, inlet and outlet sections, and internal flow regions where higher thermal and velocity gradients were expected.

To improve near-wall flow and thermal prediction accuracy, inflation layers were generated along the internal pipe surfaces, which is essential for turbulent flow analysis. Mesh quality was evaluated using parameters such as skewness and aspect ratio to ensure compliance with solver quality requirements. Finally, a mesh independence study was conducted to verify that further mesh refinement did not produce significant variations



in the simulation results, confirming the suitability of the generated mesh for reliable thermal-fluid analysis of both absorber pipe configurations.

8. BOUNDARY CONDITIONS

After meshing, boundary conditions were applied to simulate the thermal and fluid flow behaviour of both smooth and externally threaded stainless steel (SS) absorber pipes. Both pipes were assigned identical material properties, including thermal conductivity, density, and specific heat, so that any variation in heat transfer performance could be attributed only to the external threading. Water was used as the working fluid, with incompressible turbulent flow assumed at an inlet velocity of 2.5 m/s. The standard $k-\epsilon$ turbulence model was selected to accurately represent turbulent mixing and convective heat transfer in internal pipe flow. A fixed inlet velocity and constant inlet temperature were specified for both configurations, while the outlet was defined as a pressure outlet with zero gauge pressure to maintain mass continuity.

The energy equation was enabled to account for heat transfer through both the fluid and pipe wall. A uniform external heat flux was applied on the pipe surface to simulate concentrated solar radiation in a parabolic trough collector. Three heat flux conditions are 1100 W/m², 2000 W/m² and 2500 W/m², were analysed as separate simulation cases to evaluate absorber performance under varying solar intensities. No slip wall conditions and conjugate heat transfer were considered to capture conduction through the stainless steel wall and convection within the water flow. Symmetry or periodic boundary conditions were applied wherever possible to reduce computational cost while maintaining accuracy, enabling a reliable comparison between smooth and threaded absorber pipes.

9. RESULTS AND DISCUSSION

9.1 THERMAL PERFORMANCE ANALYSIS

The temperature distribution along the absorber pipes showed noticeable differences between the smooth and externally threaded configurations. The smooth pipe exhibited a gradual rise in wall and fluid temperature along the flow direction, with average fluid temperatures of 317.6 K, 332.226 K, and 341.939 K under heat fluxes of 1100 W/m², 2000 W/m², and 2500 W/m², respectively. In comparison, the externally threaded pipe produced higher wall temperatures at the thread crests and a more uniform temperature distribution, indicating improved heat absorption and transfer. The corresponding average temperatures for the threaded pipe were 334.432 K, 362.695 K, and 378.391 K, demonstrating a significant enhancement in thermal performance due to the presence of external threading.

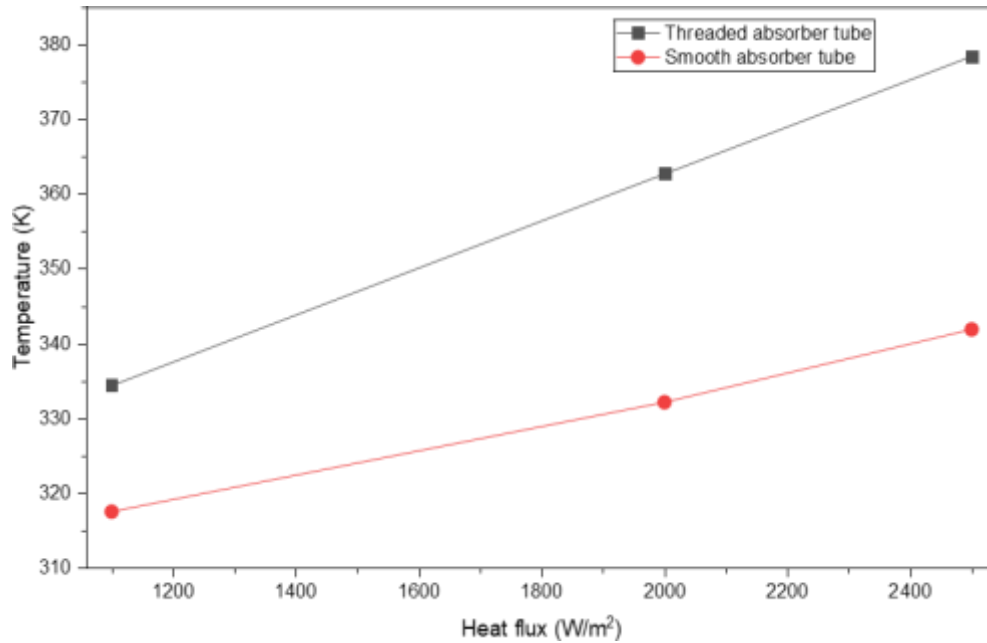


Figure 1. Graph between Temperature and Heat flux

9.2 HEAT TRANSFER RATE AND EFFICIENCY

The externally threaded pipe exhibited a higher convective heat transfer coefficient than the smooth pipe due to its increased external surface area and improved conduction paths, resulting in greater useful heat gain and higher outlet fluid temperatures. Under a heat flux of 1100 W/m², the threaded pipe achieved an average fluid temperature of 334.432 K, approximately 5.27% higher than the smooth pipe (317.6 K). At 2000 W/m², the threaded configuration reached 362.695 K, showing a 9.15% improvement over the smooth pipe (332.226 K), while at 2500 W/m² it attained 378.391 K, representing a 10.66% increase compared to 341.939 K for the smooth pipe. These results clearly demonstrate that external threading significantly enhances the heat transfer rate and overall thermal efficiency of the parabolic trough collector, with the improvement becoming more pronounced at higher heat flux values, while maintaining the same internal flow characteristics.

9.3 STREAMLINED RESULTS

Streamline analysis indicates that the externally threaded pipe promotes stronger secondary flows and enhancing convective heat transfer. In contrast, the smooth pipe shows mostly lower wall to fluid heat transfer.

Case 1, heat flux 1100 W/m² and velocity 2.5 m/s

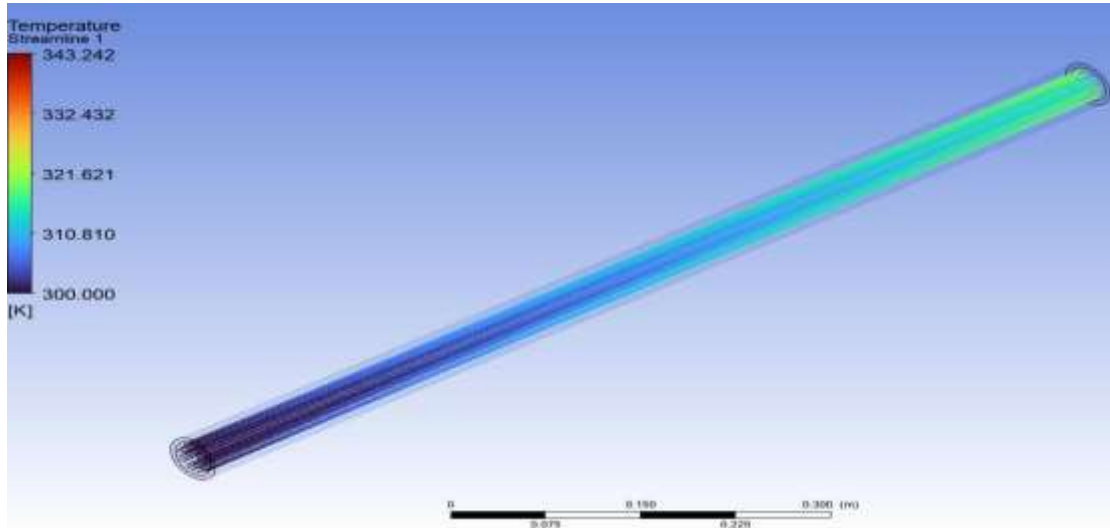


Figure 2.1 streamline for smooth absorber pipe on 1100 W/m^2

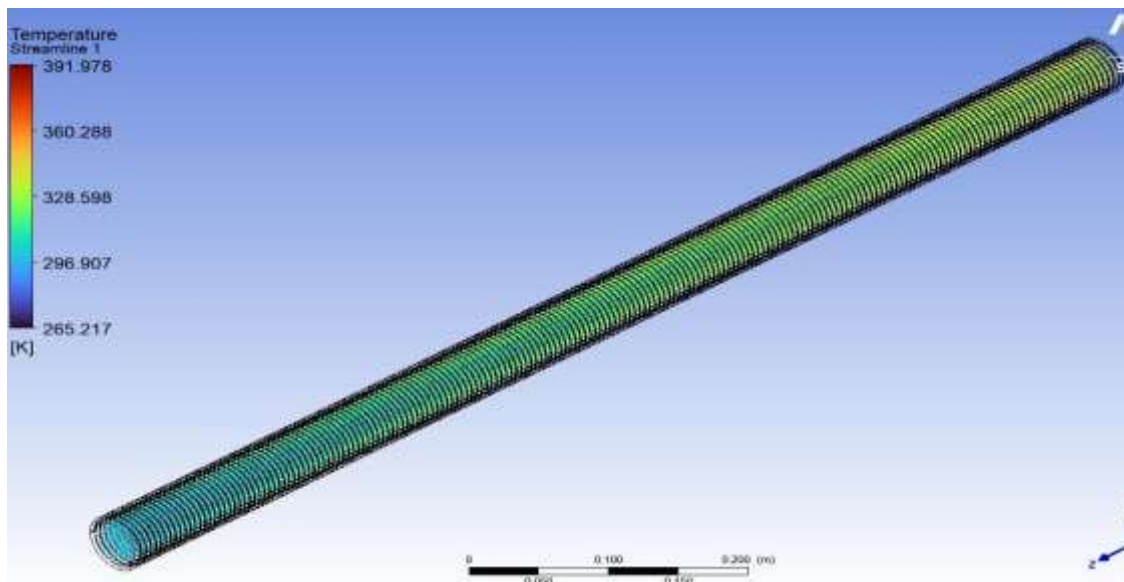


Figure 2.2 streamline for threaded absorber pipe on 1100 W/m^2

Case 2, heat flux 2000 W/m^2 and velocity 2.5 m/s

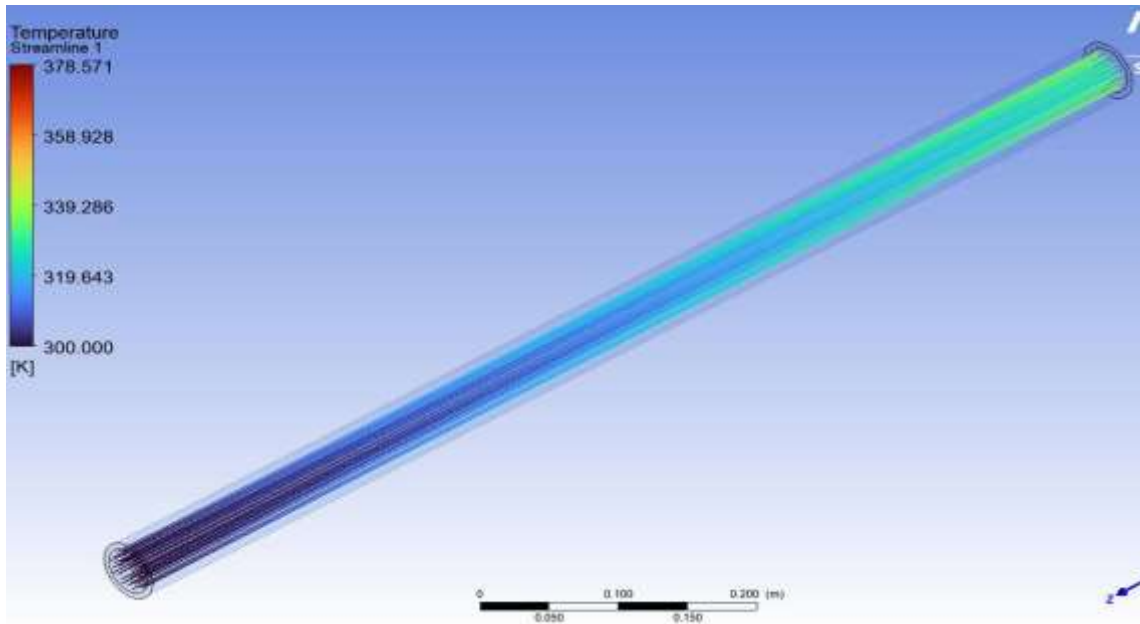


Figure 3.1 streamline for smooth absorber pipe on 2000 W/m^2

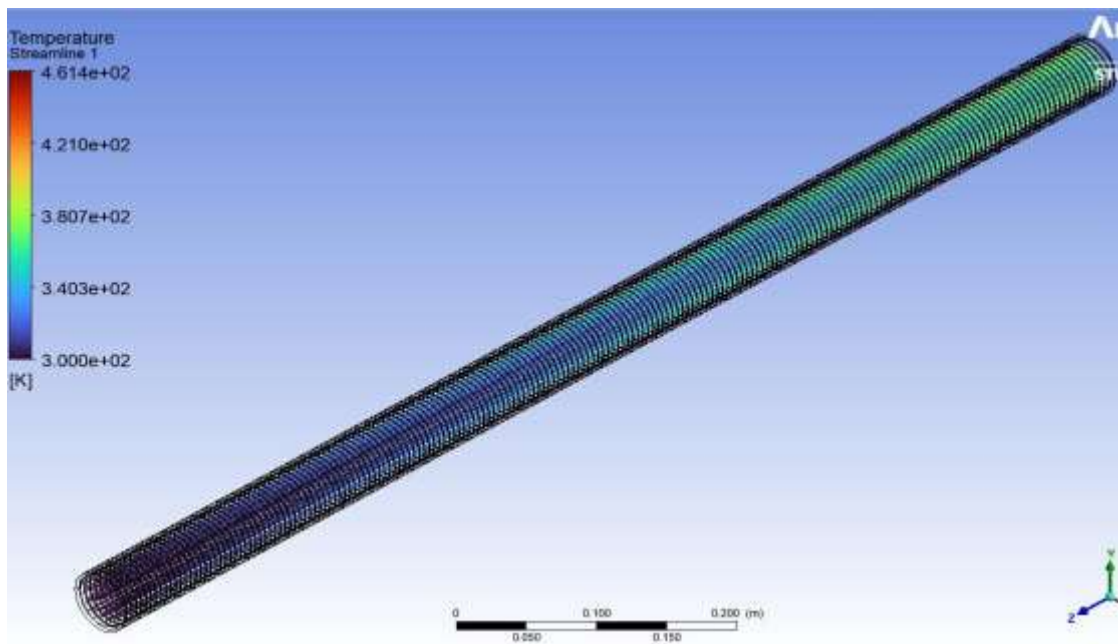


Figure 3.2 streamline for threaded absorber pipe on 2000 W/m^2

Case 3, heat flux 2500 W/m^2 and velocity 2.5 m/s

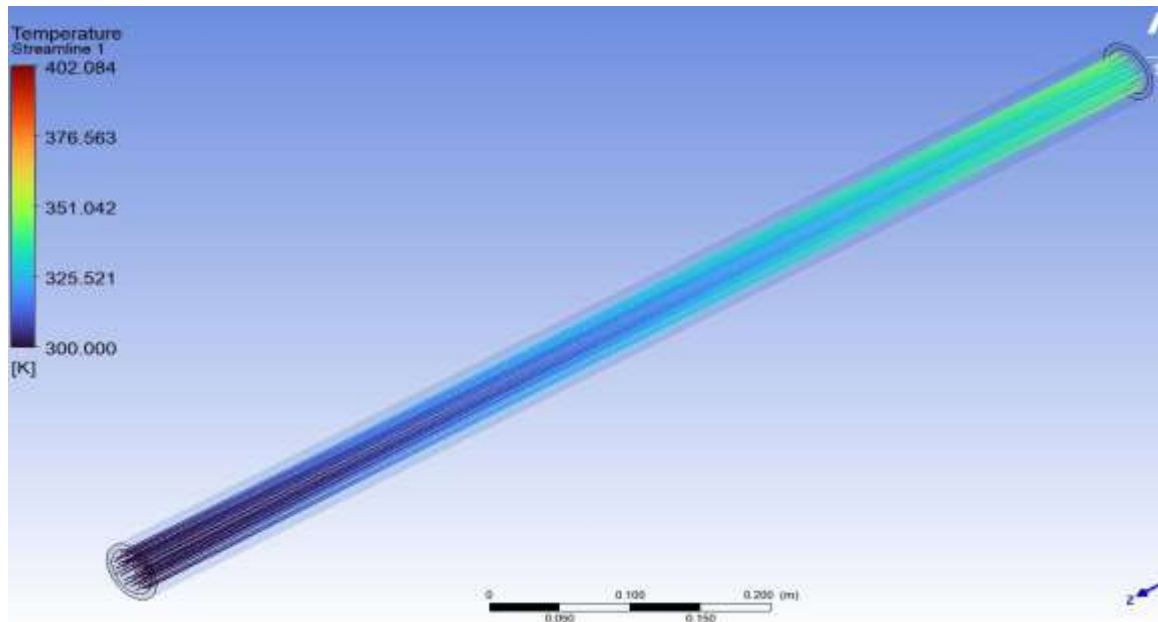


Figure 4.1 streamline for smooth absorber pipe on 2500 W/m²

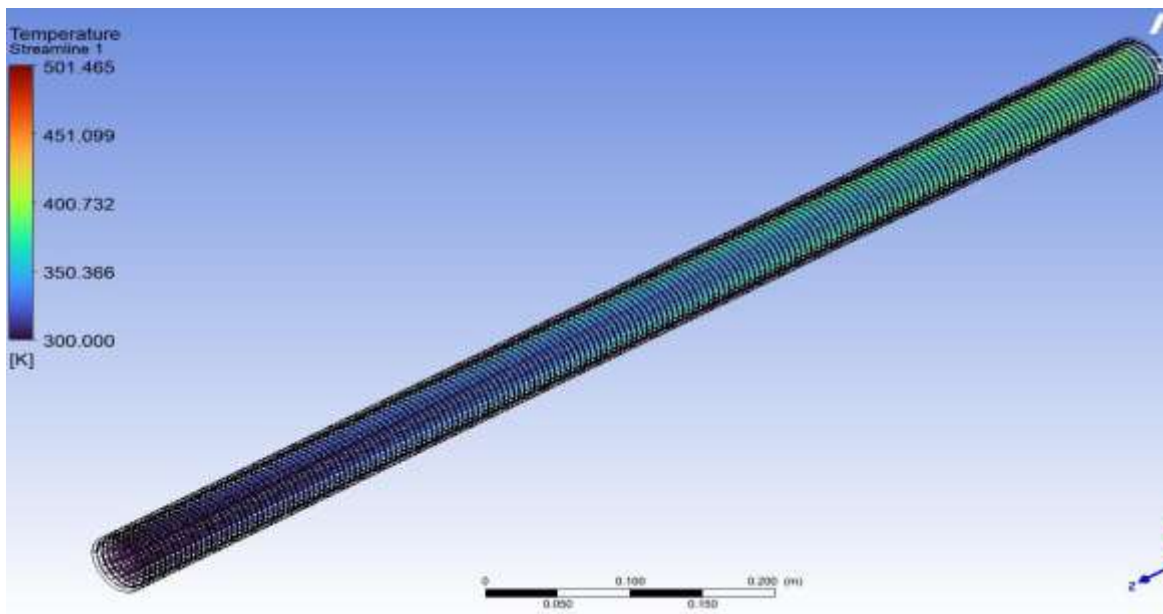


Figure 4.2 streamline for threaded absorber pipe on 2500 W/m²

10. CONCLUSION

The present study investigated the thermal performance of smooth and externally threaded stainless steel absorber pipes in a parabolic trough collector under identical operating conditions by maintaining constant material properties, internal surface characteristics, and inlet flow conditions to isolate the effect of external threading on heat transfer behaviour. The results revealed that the externally threaded absorber pipe consistently achieved higher average fluid temperatures, improved heat absorption, and greater thermal efficiency than the smooth pipe across all tested heat flux values due to the increased external surface area created by the threading, which enhanced the conduction path and promoted more effective heat exchange between the absorber tube and the working fluid. The performance advantage became more pronounced at higher heat fluxes, confirming that



external surface modification is particularly beneficial under elevated thermal loads, while streamline analyses indicated improved thermal hydraulic behaviour without affecting internal flow conditions. Overall, the findings demonstrate that incorporating external threading on absorber pipes is a simple, practical, and low cost approach for enhancing the heat transfer rate and efficiency of parabolic trough collectors, while also providing a strong foundation for future studies involving optimized thread geometries, materials, and coatings for advanced solar thermal energy systems.

REFERENCES

- [1] Ayoub Oumachtaq, Mohammed Halimi, August 2025, "Thermal performance evaluation of a parabolic trough collector receiver: A numerical study of three heat exchanger configurations," *Case Studies in Thermal Engineering*, 106303.
- [2] Hyemin Kim, Veerakumar Chinnasamy, Jeonggyun Ham, March 2025, "Parabolic trough collectors: A comprehensive review of design innovations, optimization studies and applications," *Energy Conversion and Management*, 119534.
- [3] Mohamed A. Hamada, Mohamed R. Abdo, March 2025, "Investigating the performance of solar parabolic concentrator using helical tubes, nanoparticles, and thermal storage materials," *Process Safety and Environmental Protection*, 106777.
- [4] M. Rokhforouz, M. Sheikholeslami, January 2024, "Numerical investigation of the process of melting and solidification within a parabolic trough solar collector using nanoparticles and fins," *Journal of Cleaner Production*, 140269.
- [5] Peng Liu, Zhimin Dong, June 2021, "A novel parabolic trough receiver by inserting an inner tube with a wing-like fringe for solar cascade heat collection," *Renewable Energy*, Pages 327-340.
- [6] Qiliang Wang, Honglun Yang, March 2018, "Numerical investigation and experimental validation of the impacts of an inner radiation shield on parabolic trough solar receivers," *Applied Thermal Engineering*, Pages 381-392.
- [7] Sawan Kumar Rawat, Moh Yaseen, November 2023, "Designing soft computing algorithms to study heat transfer simulation of ternary hybrid nanofluid flow between parallel plates in a parabolic trough solar collector: Case of artificial neural network and particle swarm optimization," *International Communications in Heat and Mass Transfer*, 107011.
- [8] Sarminah Samad, Salman Saeidlou, September 2025, "Energy-economy analysis of a novel spiral channeled conical turbulator inserted within the parabolic trough solar collector absorber tube," *Case Studies in Thermal Engineering*, 106462.
- [9] Sumeetkumar Kotak, Nikhilkumar Jagjivan Chotaib, November 2025, "Optimisation of a cut-tube absorber for parabolic trough collectors to minimise heat loss and pressure drop," *Applied Thermal Engineering*, 128950
- [10] Teerapath Limboonruang, Muiyiwa Oyinlola, March 2025, "Optimizing the configuration of external fins of solar receiver tubes for the solar parabolic trough collector," *Applied Thermal Engineering*, 125317.
- [11] Tianxiang Hu, Haoyu Si, December 2025, "Performance evaluation of progressively eccentric double-coated absorber tubes on boosting the techno-economic metrics of solar thermal power systems," *Applied Thermal Engineering*, 128320.
- [12] Tianxiang Hu, Trevor Hocksun Kwanb, September 2023, "Thermal performance investigation of the newly shaped vacuum tubes of parabolic trough collector system," *Energy*, 127802.