

Design of Compact Heat Exchanger for Waste Heat Recovery

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Abstract - In thermal power plants, a considerable amount of energy is lost in the form of low-grade heat, especially from turbine exhaust during the steam cycle. This rejected heat reduces overall system efficiency and increases fuel consumption. The present project focuses on improving steam recovery efficiency by utilizing a compact shell-and-tube heat exchanger designed for waste heat recovery applications. The study aims to enhance heat transfer performance by incorporating perforated circular fins and comparing the results with a conventional plain tube heat exchanger under identical operating conditions.

A three-dimensional model of the heat exchanger was developed and analyzed using computational fluid dynamics (CFD). Water was considered as the working fluid on both shell and tube sides, with controlled mass flow rates and inlet temperatures. Two configurations were evaluated: one without fins and another with perforated circular fins attached to the tube surface. The performance parameters analyzed include heat transfer rate, temperature variation, and thermal effectiveness.

The results show that the finned configuration significantly improves thermal performance. The heat transfer rate increased from approximately 8.38 MW in the plain tube design to 12.04 MW with fins. Similarly, the effectiveness improved from 0.191 to 0.274, indicating better utilization of available thermal energy. Although there was a moderate increase in pressure drop, it remained within acceptable operational limits.

The improvement in performance is mainly attributed to the increased heat transfer area and enhanced fluid turbulence caused by perforated fins. This study demonstrates that the proposed compact finned heat exchanger is an efficient and practical solution for steam heat recovery. The outcome contributes to improved energy efficiency and supports sustainable thermal system design in power plant applications.

Keywords: Waste Heat Recovery, Steam Recovery Efficiency, Shell and Tube Heat Exchanger, Perforated Circular Fins, CFD, Thermal Effectiveness.

INTRODUCTION

In thermal power plants, a large portion of energy is lost as low-grade heat, particularly from turbine exhaust during the Rankine cycle. This rejected heat is usually dissipated in the condenser, leading to reduced overall system efficiency. Recovering this waste heat is essential for improving energy utilization, reducing fuel consumption, and supporting sustainable power generation. Heat exchangers, especially shell-and-tube types, are widely used for this purpose due to their reliability and ability to operate under high temperature and pressure conditions .

Previous studies such as those by Kern, Incropera, and Kakac have focused on improving heat exchanger performance through increased surface area, turbulence enhancement, and optimized flow arrangements. While these studies highlight the effectiveness of fins in enhancing heat transfer, most conventional designs either increase system size or do not effectively balance heat transfer improvement with pressure drop limitations.

A key research gap exists in developing a compact heat exchanger that significantly enhances heat recovery without causing excessive pressure losses. This project addresses this gap by incorporating perforated circular fins into a shell-and-tube heat exchanger and comparing its performance with a plain tube configuration. The study focuses on improving steam recovery efficiency by increasing heat transfer rate and effectiveness while maintaining practical operating conditions.

PROCEDURE

The project was carried out in four main stages: design, modeling, simulation, Performance Evaluation and comparative analysis of a compact shell-and-tube heat exchanger for steam heat recovery.

1. Design and Setup

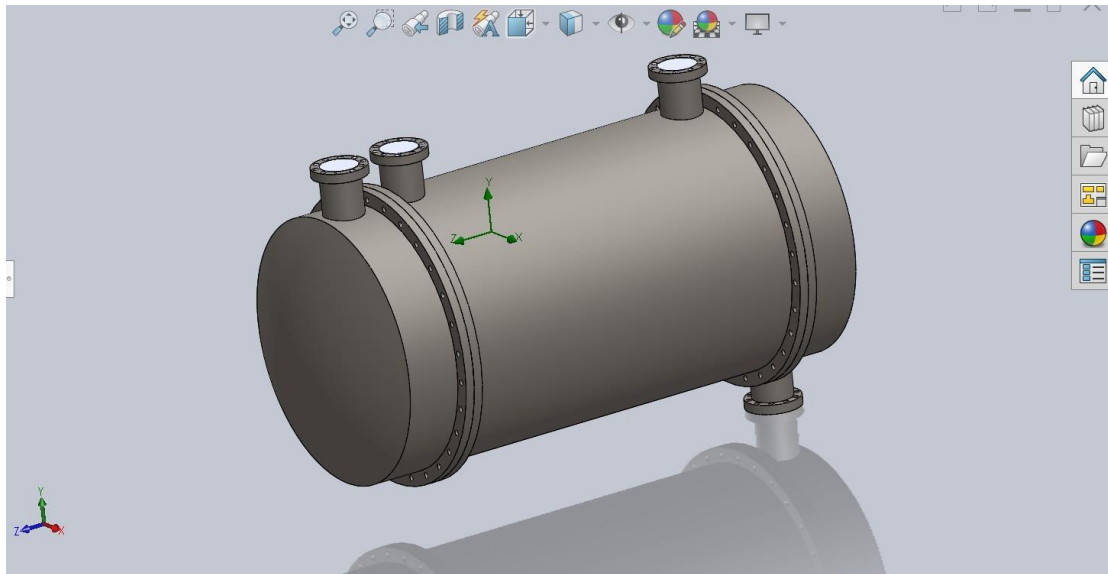


Fig 1 Heat Exchanger

A compact shell-and-tube heat exchanger was selected for waste heat recovery in steam systems. The setup consists of a cylindrical shell, multiple straight tubes, and segmental baffles to enhance shell-side flow.

Two configurations were developed:

- Plain tube heat exchanger
- Perforated circular finned tube heat exchanger

Design Data (from model):

- Tube outer diameter = 25 mm
- Fin outer diameter = 30 mm
- Fin thickness = 1 mm
- Fin type = Perforated circular fins
- Baffles used = 3 segmental baffles
- Tube material = Copper
- Shell material = Mild Steel
- Fin material = Aluminium
- Number of Fins = 290 per tube
- Number of Tube = 750
- Nozzle Inner diameter = 300mm

The fins were arranged uniformly along the tube length to increase heat transfer area and improve fluid mixing.

2. MODELING

The complete 3D model of both configurations (with and without fins) was developed using SolidWorks. Proper alignment of tubes, baffles, and shell was ensured. The fin geometry included multiple perforation holes to reduce pressure drop and enhance turbulence.

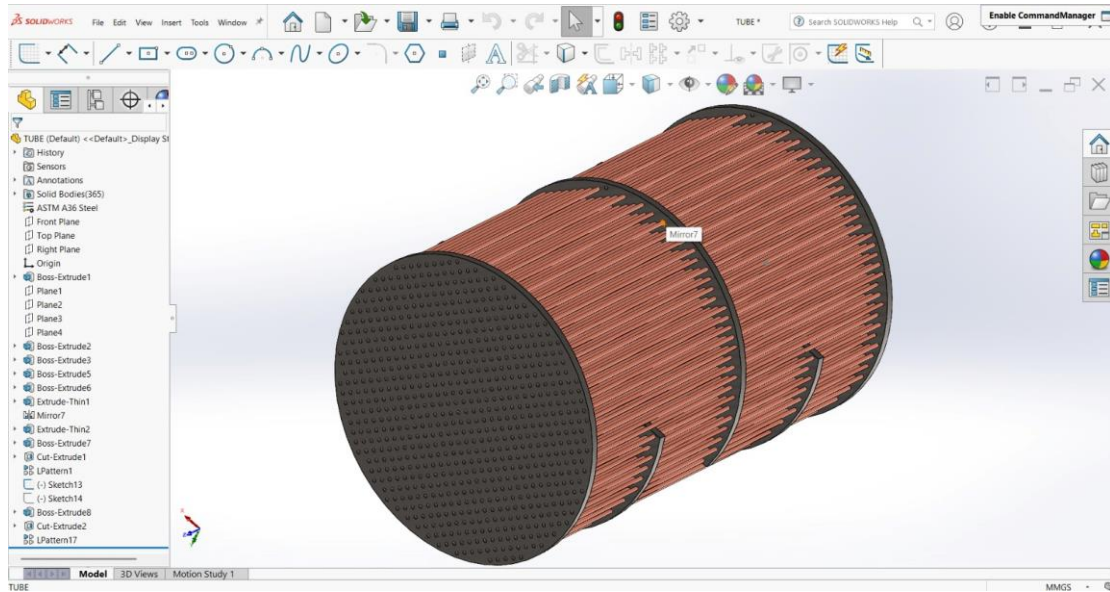


Fig 2 Baffle and Tube with out Fin

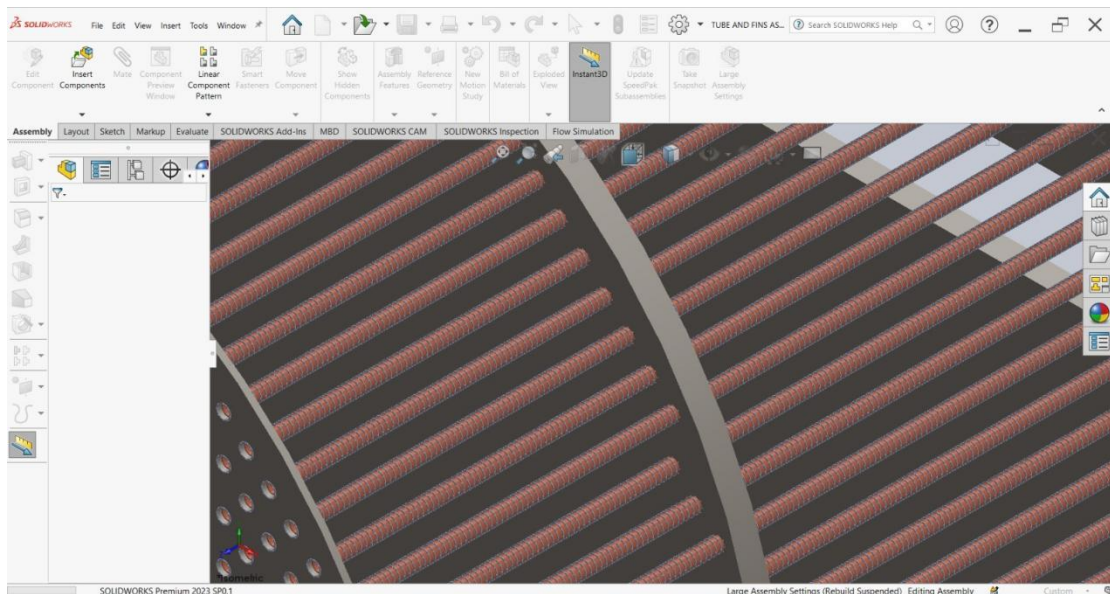


Fig 3 baffle and Tube with Fins

3. SIMULATION SETUP (CFD ANALYSIS)

The models were imported into CFD software and analyzed under steady-state conditions.

Input Parameters:

- Working fluid: Water (both shell & tube side)
- Hot fluid mass flow rate = 300 kg/s
- Cold fluid mass flow rate = 600 kg/s
- Specific heat (C_p) = 4180 J/kg·K

Inlet Conditions:

- Hot fluid inlet temperature = 70°C

- Cold fluid inlet temperature = 35°C

Boundary Conditions:

- Mass flow inlet
- Pressure outlet
- Turbulent flow model

A fine mesh was generated with refinement near:

- Tube surfaces
- Fin regions
- Baffles

4. PERFORMANCE EVALUATION

Simulation outputs obtained:

- Temperature distribution
- Velocity distribution
- Heat transfer rate
- Effectiveness

Without fins:

- Heat transfer ≈ 8.38 MW
- Effectiveness ≈ 0.191

With fins:

- Heat transfer ≈ 12.04 MW
- Effectiveness ≈ 0.274

5. COMPARISON

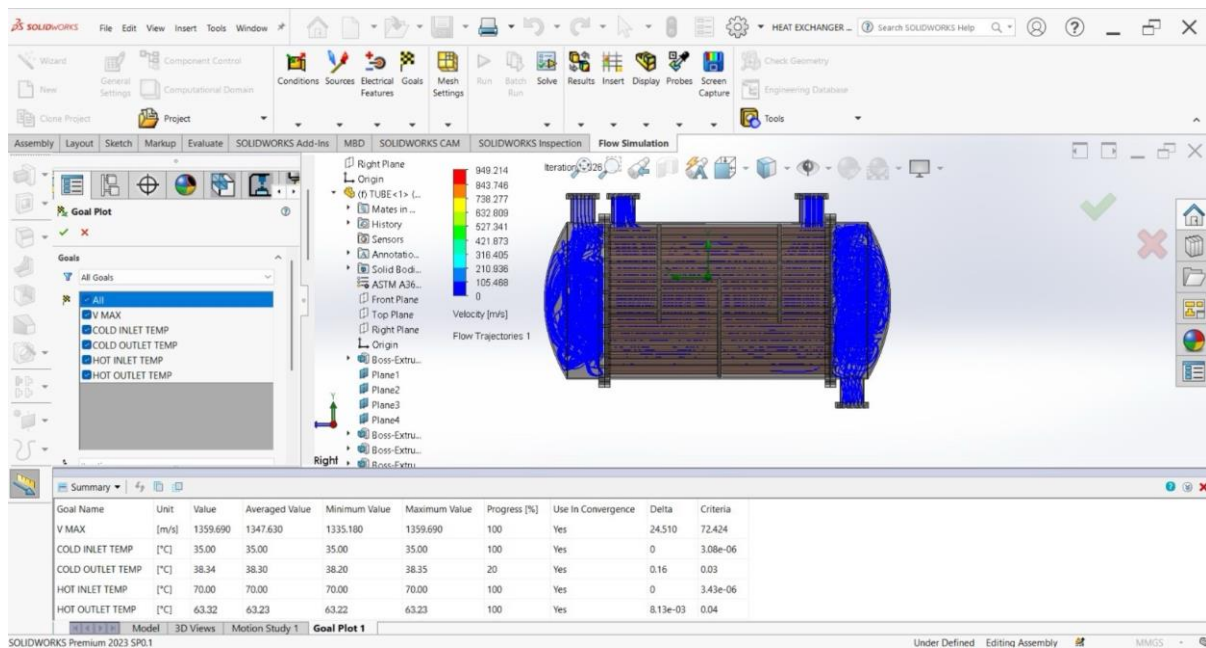


Fig 4 Result with out Fins

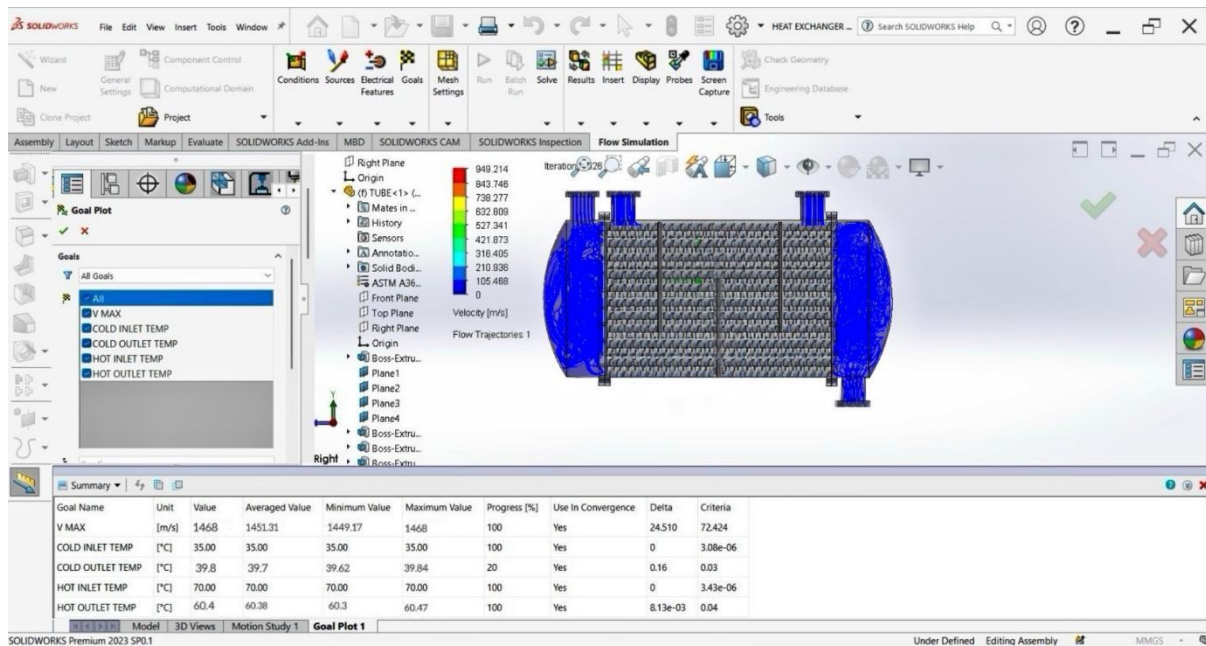


Fig 5 Result with Fins

Both models were compared under identical conditions.

- Heat transfer improved by $\approx 43\%$
- Effectiveness significantly increased
- Pressure drop increased slightly but remained acceptable

The improvement is due to:

- Increased surface area
- Enhanced turbulence from perforated fins

RESULT

The performance of the compact shell-and-tube heat exchanger was evaluated under specified operating conditions using water as the working fluid on both shell and tube sides. For the plain tube configuration, the hot fluid temperature decreased from 70°C to 63.32°C , while the cold fluid temperature increased from 35°C to 38.34°C . The calculated heat transfer rate on the hot side was approximately 8.38 MW, which closely matched the heat gained by the cold fluid, confirming the validity of the energy balance relation ($Q_h \approx Q_c$).

For the perforated finned configuration, improved thermal performance was observed. The hot fluid temperature dropped to 60.4°C , and the cold fluid temperature increased to 39.8°C . The corresponding heat transfer rate was found to be 12.04 MW on both hot and cold sides, again satisfying the energy balance condition.

The effectiveness of the heat exchanger increased from 0.191 (without fins) to 0.274 (with fins), indicating better utilization of thermal energy. The results clearly show that the addition of perforated circular fins enhances heat transfer by increasing surface area and promoting fluid mixing. Overall, the finned configuration demonstrated a significant improvement in heat recovery efficiency while maintaining acceptable operating conditions.

CONCLUSION

The present work focused on the design and performance evaluation of a compact shell-and-tube heat exchanger for steam heat recovery applications. A comparative analysis between plain tube and perforated circular fin configurations clearly showed that the addition of fins significantly improves thermal performance. The finned configuration produced a higher temperature drop on the hot fluid side and a greater temperature rise on the cold fluid side, indicating enhanced heat transfer. The heat transfer rate increased from 8.38 MW to 12.04 MW, and the effectiveness improved from 0.191 to 0.274, demonstrating better utilization of

available thermal energy. Although the pressure drop increased slightly due to fin addition, it remained within acceptable operational limits. These results confirm that perforated fins effectively increase surface area and promote turbulence, leading to improved heat recovery efficiency.

From this study, it can be inferred that compact finned heat exchangers are a practical and efficient solution for recovering waste heat in thermal systems. For future work, the design can be further optimized by modifying fin geometry, spacing, and perforation size to achieve better performance. Experimental validation using real steam conditions and extension to other industrial applications can also enhance the reliability and applicability of the system.

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