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Optimized Water Jacket Pin-Fin design for Reducing Pressure Drop in Cooling System

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Abstract

In the electric vehicle and solar industries, the cooling performance of power conversion devices is a key factor in ensuring system stability and efficiency. Liquid cooling offers superior heat dissipation, but excessive pressure drop can reduce cooling efficiency. The pin-fin structure inside a water jacket enhances heat transfer; however, an unoptimized design may lead to excessive pressure drop. This study investigates the impact of pin-fin shape, count, and height on pressure drop and thermal performance using CFD simulations with EGW-50 coolant. The findings emphasize the importance of optimizing pin-fin design to achieve an optimal balance between pressure drop and cooling efficiency.

Introduction

1.1 Research Background

As the demand for high-efficiency energy solutions increases, effective thermal management has become a critical factor in the electric vehicle (EV) and solar power industries. Power conversion components in these applications generate significant heat, which must be efficiently dissipated to ensure system stability and performance. Liquid cooling systems are widely used due to their superior heat removal capabilities compared to air cooling. However, excessive pressure drop within the cooling system can negatively affect coolant flow rate, leading to higher thermal resistance and reduced cooling efficiency.

One of the key design elements in liquid cooling systems is the water jacket, which houses coolant flow passages to extract heat from critical components. The internal structure of the water jacket, particularly the pin-fin design, plays a crucial role in enhancing heat transfer by increasing the surface area and promoting turbulent flow. However, an improper pin-fin design can significantly increase pressure drop, reducing the overall cooling performance. Thus, an optimal balance between thermal performance and pressure drop is necessary when designing water jackets for EV and solar applications.

1.2 Research Objectives

This study aims to analyse the effects of varying pin-fin design parameters—shape, count, and height—on pressure drop within a water jacket and derive an optimized design. To achieve this, Computational Fluid Dynamics (CFD) simulations were conducted to evaluate pressure drop and cooling performance.

Theoretical Background

2.1 Relationship between Pressure drop and heat transfer

An increase in pressure drop is likely to reduce the flow rate, which can lead to a decrease in the heat transfer coefficient. Thermal resistance (R_t) is defined as follows:

$$R_t = \frac{1}{hA}$$

where (h) is the heat transfer coefficient (W/m²K), and (A) is the heat exchange surface area (m²). If the pin-fin design is not optimized, fluid flow may be restricted, leading to an increase in pressure drop and a subsequent reduction in flow rate. As a result, the heat transfer coefficient (h) decreases, causing an increase in thermal resistance.

Research Methodology

In this study, Ansys ICEPAK was used to analyze the pressure drop characteristics by modifying the pin-fin design within the water jacket. The simulation was conducted using EGW-50 coolant as the working fluid. The flow rate was set to 30LPM, and the inlet temperature was 65°c. the study focused on a Qdual3 6 module water jacket design to evaluate the impact of pin-fin modifications on pressure drop characteristics.

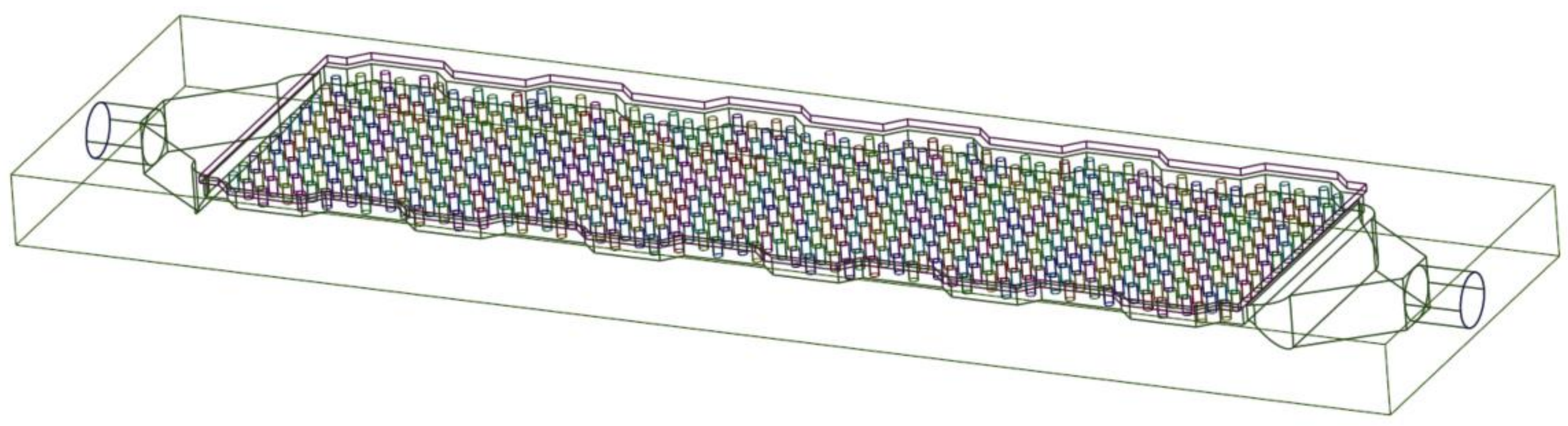

Fig. 1 Qdual3 water jacket design

Design Variables

To assess various design configurations, three key design variables were considered:

1.Fin Shape: Oval and Round

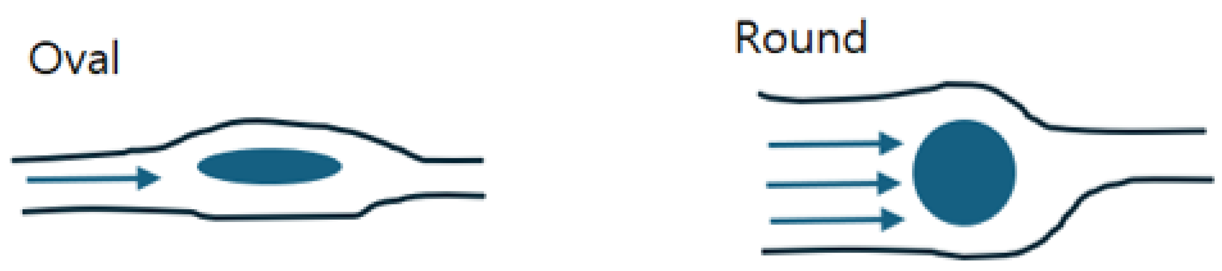

Fig. 2 Fin shape

2.Fin count : 616ea and 858ea

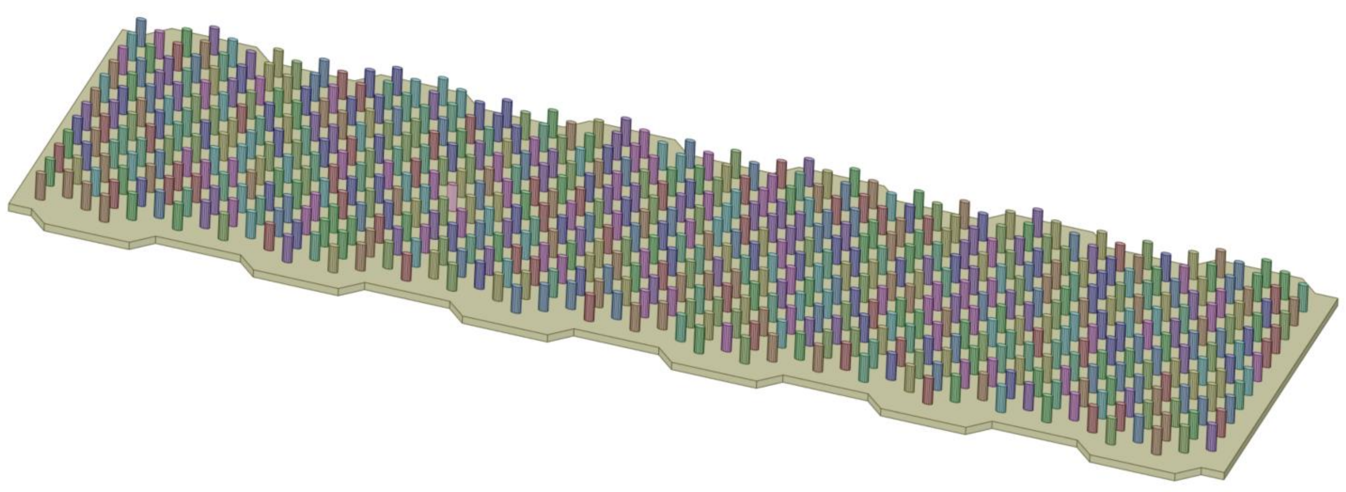

Fig. 3 Fin count

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3.Fin Height : 6mm and 9mm

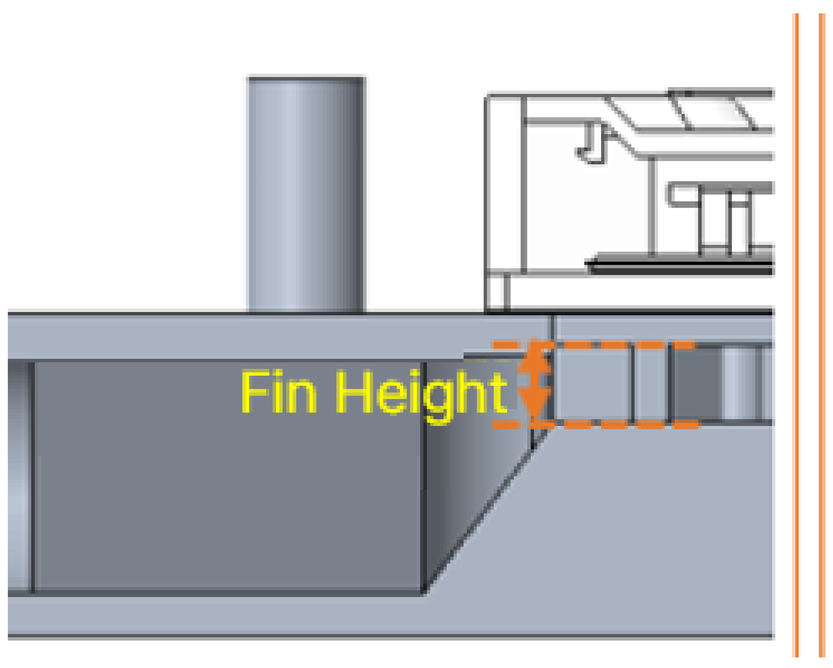
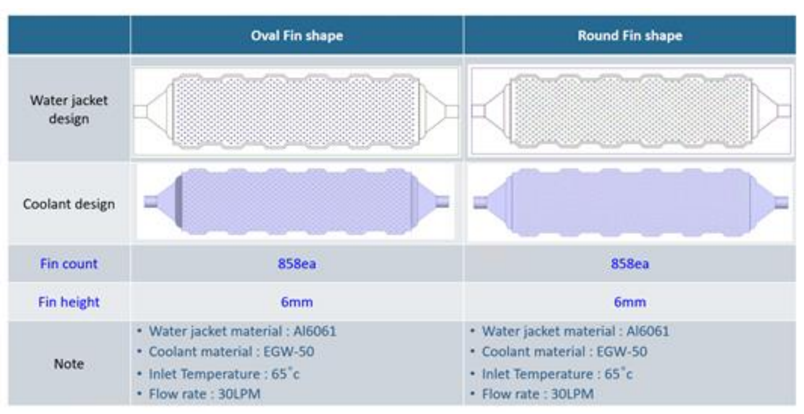


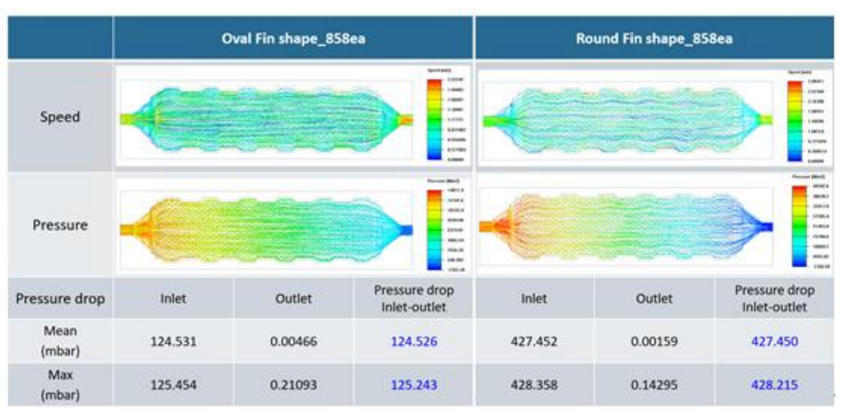
Fig. 4 Fin Height

Results and Analysis

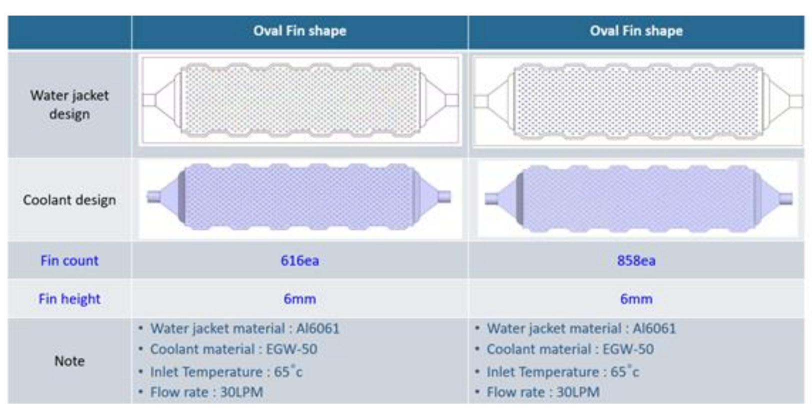
Pressure drop in a liquid cooling system is influenced by factors such as flow resistance, channel geometry and turbulence intensity. In pin-fin structures, variations in shape, density, and height directly impact the fluid flow characteristics, leading to different pressure drop behaviors.
The analysis of pressure drops variations based on pin-fin design revealed the following results:

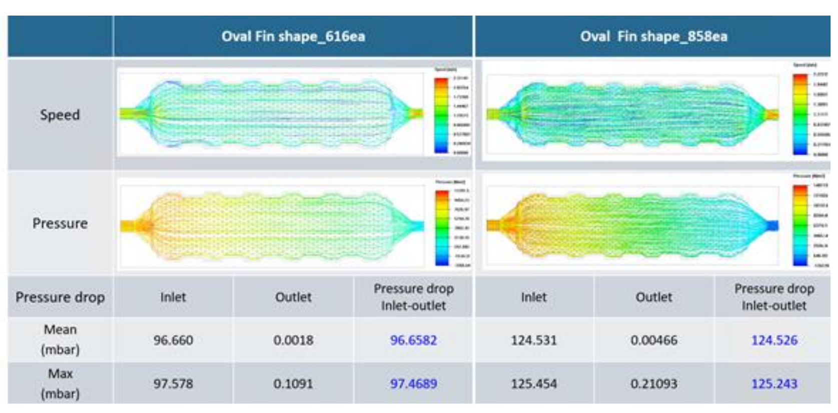
1. The round fin shape exhibited a significantly higher-pressure drop compared to the oval pin shape. This is likely due to the increased flow resistance caused by the abrupt flow separation and higher drag coefficient associated with round fins.



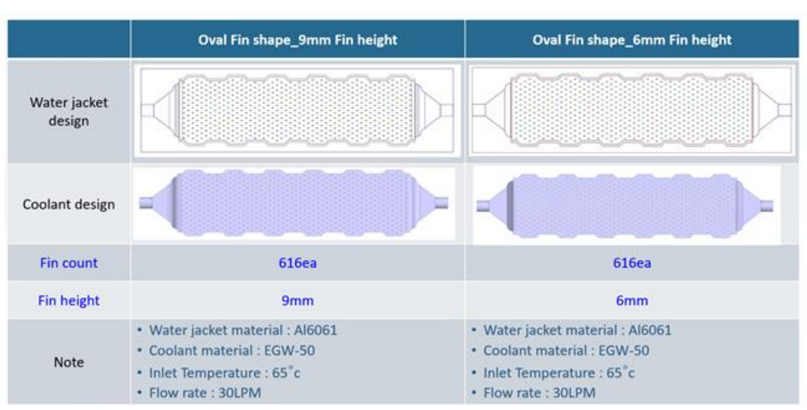


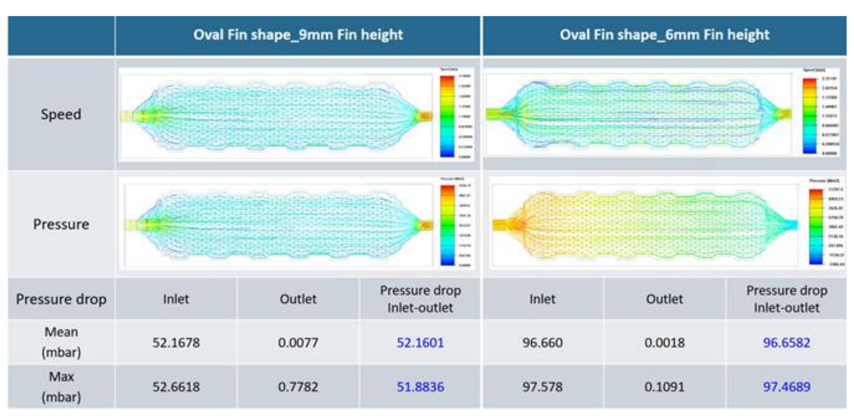
2. As the pin density increases, the pressure drops also increase. A greater number of fins obstructs the flow path, leading to higher frictional losses and greater energy dissipation.





3. An increase in fin height resulted in a decrease in pressure drop. Taller fins create a larger flow passage between them, reducing flow constriction and minimizing pressure loss.

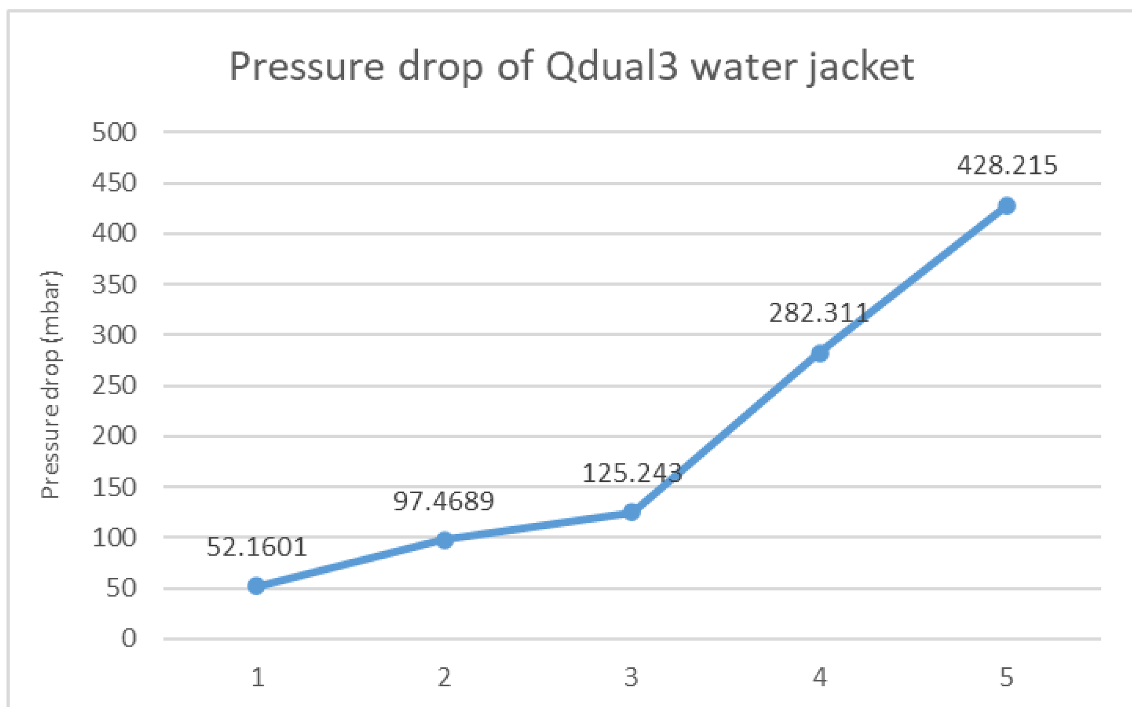




Conclusion

This study analyzed the impact of pin-fin design parameters on pressure drop within a water jacket using CFD simulations. The results demonstrate that fin shape, fin height, and fin count significantly influence pressure drop characteristics.
These findings highlight the need to optimize pin-fin design to achieve a balance between efficient heat transfer and minimal pressure drop in liquid cooling applications.
Among the three design parameters, pin shape had the greatest impact on pressure drop, followed by pin height and pin count.
These findings emphasize the importance of optimizing pin-fin design to achieve an optimal balance between cooling performance and pressure drop in liquid cooling applications.

#	Fin shape	Fin count (ea)	Fin height (mm)	Pressure drop (mbar)
1	Oval	616ea	9mm	52.1601
2	Oval	616ea	6mm	97.4689
3	Oval	858ea	6mm	125.243
4	Round	622ea	6mm	282.311
5	Round	858ea	6mm	428.215



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