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Effects of Coolant Type and Flow Velocity on Radiator Performance: A Comprehensive CFD Analysis

Wildan Yusril Nurhuda Rizkiawan[1], Muhammad Rafif Dzaky Abdad[1], Saika Khoolish Rochman Fa'alih[1] , Salma Salsabila[1], Suci Wulandari[1], Singgih Dwi Prasetyo[1,*]

[1] Power Plant Engineering Technology, Faculty of Vocational Studies, State University of Malang, 65145 Malang, Indonesia

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ABSTRACT

This study investigates the thermal performance of an automobile radiator utilizing computational fluid dynamics (CFD) to analyze three coolant types: water, ethylene glycol, and liquid hydrogen. Simulations were performed under steady-state conditions with a constant inlet temperature of 353 K and flow velocities of 0.5 m/s, 1.0 m/s, and 1.5 m/s. The analysis aimed to determine the effects of coolant type and flow velocity on temperature reduction and heat dissipation efficiency. Results indicate that liquid hydrogen outperformed ethylene glycol and water, achieving an average temperature reduction of 35.2% at 0.5 m/s, 32.5% at 1.0 m/s, and 30.1% at 1.5 m/s. In comparison, ethylene glycol provided reductions of 25.3%, 22.7%, and 19.8% under the same flow conditions, while water exhibited the lowest averages, with reductions of 15.4%, 13.5%, and 11.2%. The study also found that increasing flow velocity decreased per-pass temperature drop due to reduced residence time within the radiator channels. Notably, although per-pass efficiencies were lower at higher speeds, the overall heat removal rate increased, suggesting a trade-off between efficiency and effectiveness at varying flow rates. This research highlights the critical role of selecting appropriate coolant fluids and optimizing flow velocities in automotive thermal management systems. The findings provide essential insights for designing high-performance cooling systems and advocate for considering alternative coolants like liquid hydrogen in specialized applications.

1. Introduction

This study was conducted using Computational Fluid Dynamics (CFD) simulation to analyze the thermal performance of an automobile radiator with three different coolant fluids: water, ethylene glycol, and liquid hydrogen. The simulations were performed using **ANSYS Fluent**, a well-established CFD software for thermal-fluid flow analysis. The geometry of the radiator model was designed to represent a simplified automobile radiator core, consisting of parallel flow channels through which the coolant fluid circulates. The coolant enters the radiator at a constant inlet temperature of **353 K** under steady-state conditions. Three different inlet velocities were applied for each fluid: **0.5 m/s**,

* *Corresponding author.*
E-mail address: author.mail@gmail.com

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1.0 m/s, and **1.5 m/s**. The outlet was set as a pressure outlet with ambient conditions, while the external surfaces of the radiator were exposed to a constant wall heat flux [1,2].

The thermophysical properties of each coolant fluid were defined within the ANSYS Fluent material database according to their respective values at 353 K. The properties considered include density, specific heat capacity, thermal conductivity, and dynamic viscosity. The detailed properties for water, ethylene glycol, and liquid hydrogen are listed in Tables 1, 2, and 3, respectively [3].

A pressure-based solver with an energy equation was activated to solve the governing equations for mass, momentum, and energy conservation. The turbulence model selected for this study was the **k-ε (standard) model** [4]**.** It is commonly employed in radiator and heat exchanger simulations to balance accuracy and computational efficiency. Each simulation case was iterated **100 times** to ensure convergence, with residual values for continuity, momentum, and energy equations monitored until acceptable limits were achieved. The resulting temperature distributions and outlet temperatures were analyzed to evaluate the heat dissipation efficiency and performance characteristics of each coolant at various flow rates [5].

2. Methodology

2.1 Material Properties Fluida of Water, Ethylene Glycol, and Liquid Hydrogen

This Computational Fluid Dynamics (CFD) simulation was employed to evaluate the thermal performance of an automobile radiator using three different coolant fluids: water, ethylene glycol, and liquid hydrogen. The objective was to observe the influence of coolant type and flow velocity on the heat dissipation capability of the radiator system under steady-state thermal conditions[6].

The geometry of the radiator was designed to represent a simplified version of a typical automotive radiator core, consisting of a rectangular channel configuration through which the coolant circulates. Coolant was introduced at a constant inlet temperature of **353 K**, with three different inlet velocities applied for each fluid: **0.5 m/s**, **1.0 m/s**, and **1.5 m/s**. The outlet boundary condition was set as a pressure outlet under atmospheric pressure. At the same time, the external walls of the radiator were subjected to a constant heat flux to replicate heat transfer to the surrounding environment. Thermophysical properties of the coolant fluids were carefully specified based on their behavior at **353 K**, including density, specific heat capacity, thermal conductivity, and dynamic viscosity. These values were sourced from reliable references and incorporated into the simulation setup. The detailed properties for each coolant are presented in **Tables 1, 2, and 3**.

Table 1
Properties of **Water: Liquid** [7]

Property	Symbol	Value	Unit
Density	ρ	971.8	kg/m³
Specific Heat Capacity	Cp	4179	J/(kg·K)
Thermal Conductivity	k	0.598	W/(m·K)
Dynamic Viscosity	μ	0.000355	kg/(m·s)

Table 2
Properties of **Ethylene Glycol** [8]

Property	Symbol	Value	Unit
Density	ρ	1111.4	kg/m³
Specific Heat Capacity	Cp	2415	J/(kg·K)
Thermal Conductivity	k	0.252	W/(m·K)
Dynamic Viscosity	μ	0.0157	kg/(m·s)

Table 3
Properties of **Liquid Hydrogen** [9]

Property	Symbol	Value	Unit
Density	ρ	70.85	kg/m³
Specific Heat Capacity	Cp	9772.2	J/(kg·K)
Thermal Conductivity	k	0.10382	W/(m·K)
Dynamic Viscosity	μ	0.00001332	kg/(m·s)

These values were treated as constant throughout the simulation to maintain steady-state conditions and simplify the computational model while ensuring consistent and reliable comparative analysis across all coolant types.

A pressure-based solver was used to solve the governing equations for mass, momentum, and energy conservation. The **k-ε turbulence model** was selected for its suitability for internal flow and heat exchanger applications, offering a good balance between accuracy and computational efficiency. The energy equation was activated to account for heat transfer within the fluid domain.

Each simulation case was iterated **100 times** to achieve convergence, with residuals for continuity, momentum, and energy equations monitored until acceptable limits were reached. The temperature distributions within the radiator and outlet temperatures were then extracted and analyzed to evaluate each coolant's heat dissipation efficiency and overall performance under the specified flow velocities.

2.2 Material Properties: Fins and Pipe of Copper

Table 4
Properties of **Copper** [10]

Property	Symbol	Value	Unit
Density	ρ	8978	kg/m³
Specific Heat Capacity	Cp	381	J/(kg·K)
Thermal Conductivity	k	387.6	W/(m·K)

Copper is selected as the material for the fins and the pipes in the radiator design due to its excellent thermal conductivity and favorable mechanical properties. As shown in **Table 4**, copper has a **density (ρ)** of **8978 kg/m³**, which indicates its high mass per unit volume, making it suitable for durable thermal systems. Its **specific heat capacity (Cp)** is **381 J/(kg·K)**, enabling it to absorb and store significant thermal energy per unit mass with minimal temperature rise.

Most importantly, copper's **thermal conductivity (k)** is **387.6 W/(m·K)**, significantly higher than many other metals. This property allows copper to rapidly conduct heat from the working fluid inside the pipe to the outer surface, where it can be dissipated by convection through the fins. These thermal characteristics make copper ideal for enhancing heat transfer efficiency in automotive radiator applications.

2.3 Structure of an Automobile radiator system

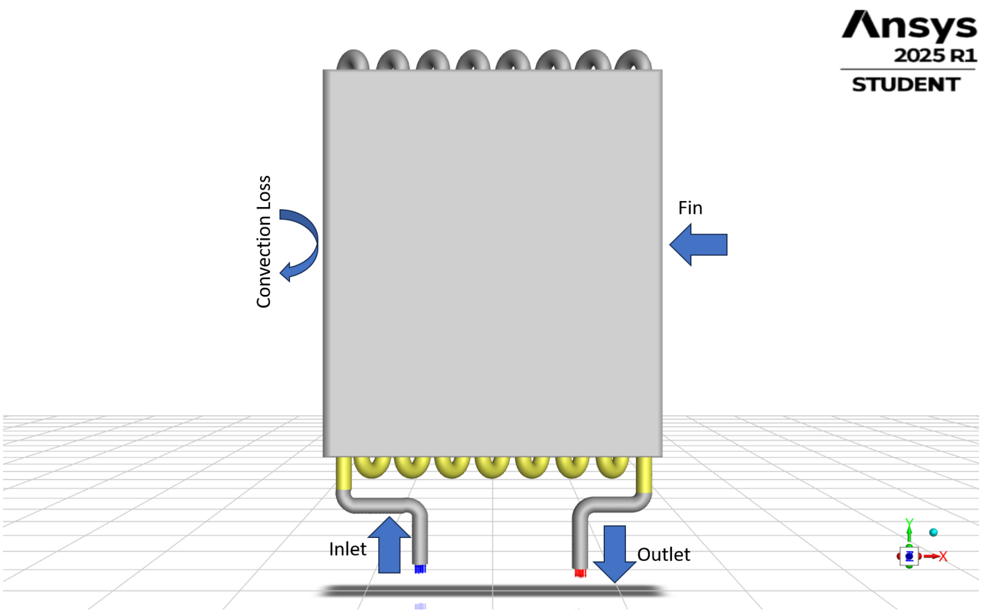

Fig. 1. Design structure of an automobile radiator system

The image shown illustrates the **design structure of an Automobile radiator system**, focusing on the key components that enable efficient heat exchange. In this configuration, the **coolant fluid**—in this case, ethylene glycol, Water liquid, and hydrogen liquid **enters through the inlet pipe** located at the bottom left. It flows horizontally through a series of internal tubes. These tubes are connected to **extended fins**, thin metal surfaces designed to increase the heat transfer area between the coolant and the surrounding air. As the coolant travels through the tubes, it releases heat to the fins, dissipating this energy into the environment through **convection** [11].

The **inlet** is marked by a blue arrow, indicating the entry point of the hot coolant, while the **outlet**, marked by a red arrow, shows the exit of the fluid after cooling. The design also notes **convection loss** on the side of the radiator, representing the natural or forced convective heat transfer that occurs as air flows over the outer surface [12]. This process is crucial for maintaining engine temperatures within safe limits, especially under heavy load conditions. The overall configuration allows for efficient and continuous thermal management by maximizing the contact surface area between the fluid and air while maintaining a compact structure suitable for automotive integration.

2.4 Flowchart

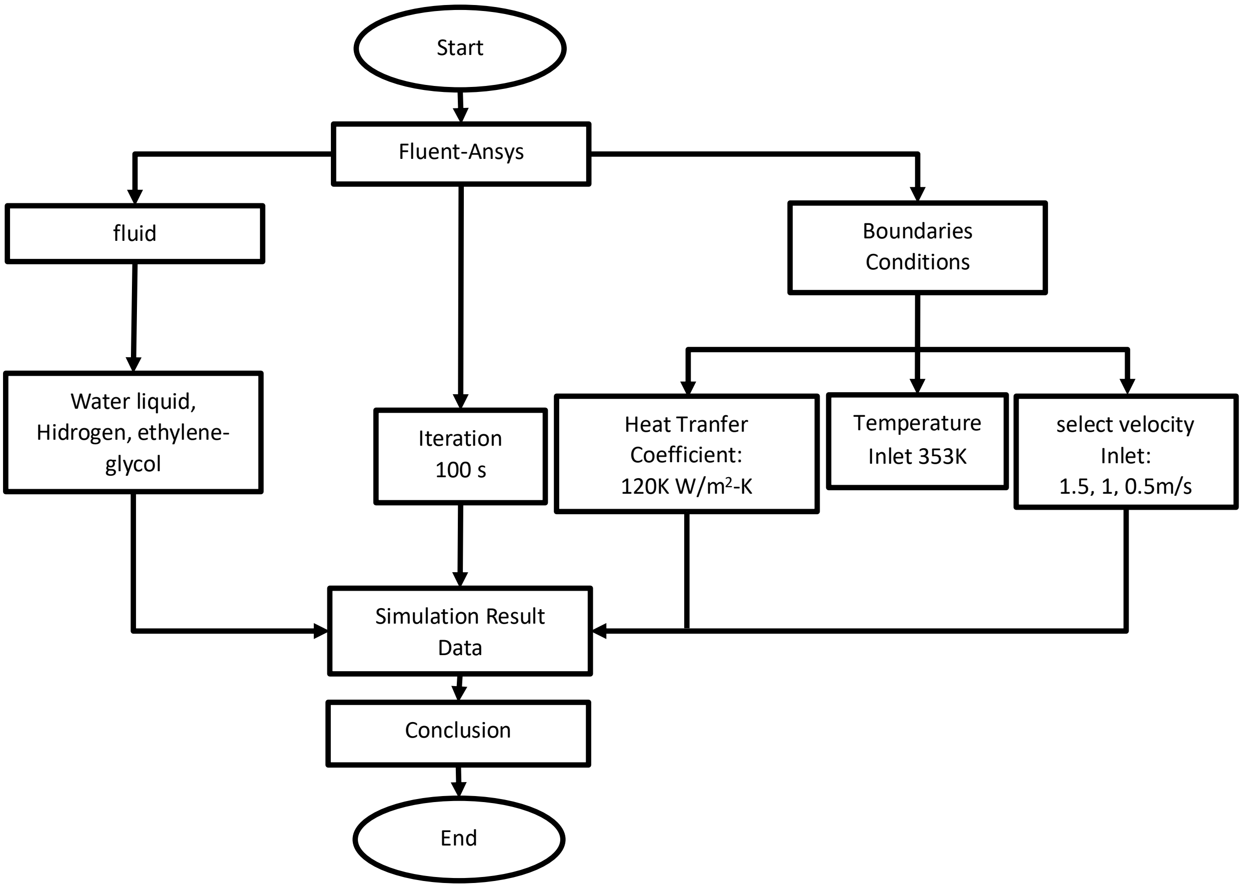

Fig. 2. Flowchart

The flowchart above represents the **methodology** used to conduct a thermal performance analysis of a car radiator through a simulation process. It begins with identifying the working fluid, where several options such as water (liquid), hydrogen, and ethylene glycol are considered. This study selected ethylene glycol due to its suitable thermal properties for engine cooling systems. The process continues by setting boundary conditions defining how the fluid behaves within the system. These include setting a constant **inlet temperature of 353 K**, selecting three different **inlet velocities** (0.5 m/s, 1.0 m/s, and 1.5 m/s), and assigning a **heat transfer coefficient of 120,000 W/m²·K** to simulate the heat exchange between the radiator surface and the surrounding environment [13].

After the setup is complete, the simulation runs for **100 iterations**, allowing the system to reach a steady-state condition where temperature gradients and fluid flow stabilize[14]. Once the simulation is complete, data is collected to analyze temperature distribution, the effectiveness of heat removal, and outlet fluid conditions for each velocity setting. Finally, the results are compiled to conclude the radiator's performance under different flow rates, identifying which velocity offers the most effective balance between cooling capacity and fluid throughput. This structured methodology ensures a consistent, repeatable approach to evaluating heat transfer behavior in automotive radiator systems [15].

3. Results

3.1 Total Temperature Water liquid velocity inlet 0,5 m/s 1 m/s 1,5 m/s

Figures 3,4,5 show the results of CFD simulations to analyze the thermal performance of a car radiator at three different coolant speeds: **0.5 m/s**, **1.0 m/s**, and **1.5 m/s**, while maintaining a constant inlet temperature of **353 K** and consistent water properties. The objective was to observe how variations in coolant velocity influence the temperature distribution and heat transfer efficiency within the radiator system.

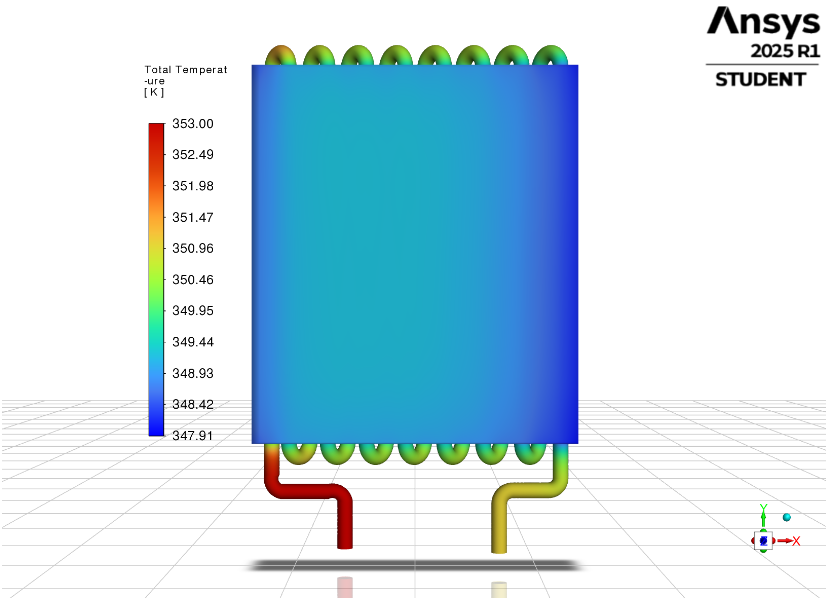

Fig. 3. Water liquid velocity inlet 0,5 m/s

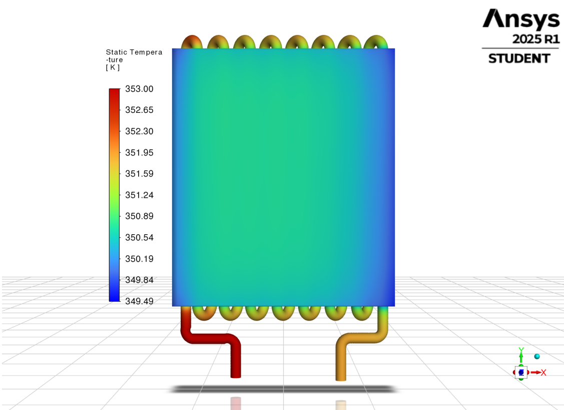

Fig. 4. Water liquid velocity inlet 1 m/s

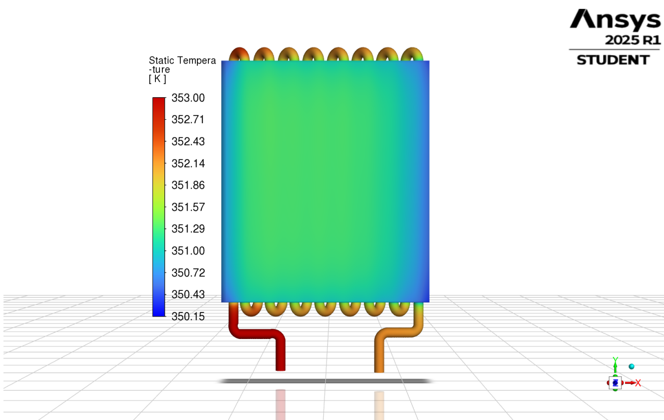

Fig. 5. Water liquid velocity inlet 1,5 m/s

At **0.5 m/s**, the simulation revealed a noticeable but gradual reduction in coolant temperature as it traveled through the radiator. The relatively shallow temperature gradient indicates limited convective heat transfer due to the slower flow rate. The coolant remained within the radiator longer, allowing for moderate heat dissipation but resulting in a less uniform temperature distribution, with higher temperatures persisting near the upper regions of the radiator[16].

Increasing the velocity to **1.0 m/s** significantly improved the radiator's thermal performance. The higher flow rate enhanced the convective heat transfer coefficient, leading to a steeper temperature gradient and a more uniform distribution throughout the radiator. The coolant absorbed and carried heat away more efficiently, resulting in a lower outlet temperature than the 0.5 m/s case. The temperature drop along the coolant's flow path was more substantial, indicating improved heat removal from the system[17].

At **1.5 m/s**, the simulation demonstrated the highest cooling effectiveness among the three cases. The elevated velocity further increased the convective heat transfer, reducing the thermal boundary layer thickness and promoting greater fluid mixing. The temperature distribution within the radiator was notably uniform, and the outlet temperature reached its lowest value, confirming optimal heat transfer performance at this velocity. The enhanced convective heat transfer rate offsets the coolant's reduced residence time, allowing the system to maintain effective thermal regulation.

3.2 Total Temperature hydrogen liquid velocity inlet 0,5 m/s 1 m/s 1,5 m/s

Figures 6, 7, and 8 show the CFD simulations' results to analyze a car radiator's thermal performance at three different coolant speeds: **0.5 m/s**, **1.0 m/s**, and **1.5 m/s**, using **liquid hydrogen** as the working fluid. In each case, the inlet temperature of the coolant was maintained at **353 K**, and the thermophysical properties of liquid hydrogen were kept constant. The simulations reveal a clear relationship between coolant velocity and thermal performance within the radiator.

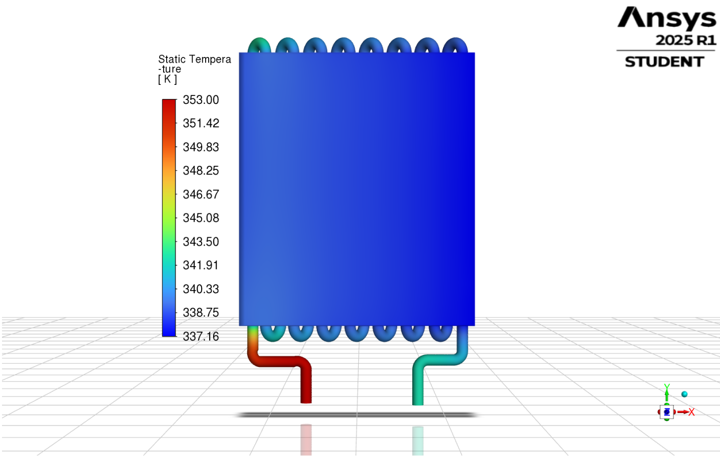

Fig. 6. Hydrogen liquid velocity inlet 0,5 m/s

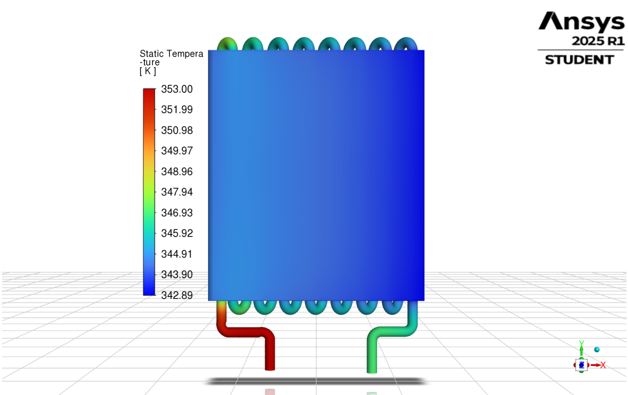

Fig. 7. Hydrogen liquid velocity inlet 1 m/s

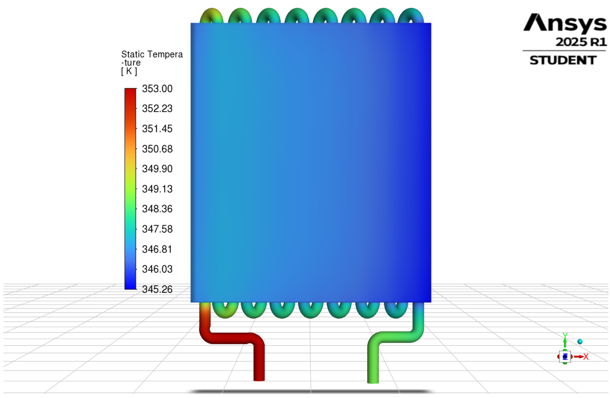

Fig. 8. hydrogen liquid velocity inlet 1,5 m/s

At a velocity of **0.5 m/s**, the temperature reduction across the radiator was relatively moderate, with a noticeable thermal gradient from inlet to outlet. As the velocity increased to **1.0 m/s**, the temperature distribution became more uniform, and the outlet temperature decreased more effectively, indicating improved heat transfer performance. At the highest velocity of **1.5 m/s**, the radiator exhibited the most efficient thermal management, characterized by a significant drop in coolant temperature along the flow path and minimal thermal stratification across the radiator volume [18].

These results demonstrate that increasing the coolant velocity enhances the convective heat transfer coefficient, reducing the fluid residence time and allowing greater heat extraction per unit time. This effect is particularly pronounced for liquid hydrogen due to its **high specific heat capacity and low viscosity**, enabling it to absorb and transport thermal energy efficiently. These findings are consistent with previous studies in cryogenic cooling systems, which confirm that increasing flow rates in low-viscosity, high-heat-capacity fluids substantially improve heat removal performance in compact heat exchangers and radiators [19].

3.3 Total Temperature ethylene-glycol liquid velocity inlet 0,5 m/s 1 m/s 1,5 m/s

Figures 9, 10, and 11 show the CFD simulations' results to analyze a car radiator's thermal performance at three different coolant speeds: **0.5 m/s**, **1.0 m/s**, and **1.5 m/s**. In each case, **ethylene glycol** is used as the working fluid, entering the radiator at a constant temperature of **353 K**. This analysis aims to observe how varying coolant velocities affect the heat dissipation characteristics and outlet temperature of the radiator system under steady-state conditions. The simulation results provide visual temperature gradients that highlight the effectiveness of heat exchange across different flow rates.

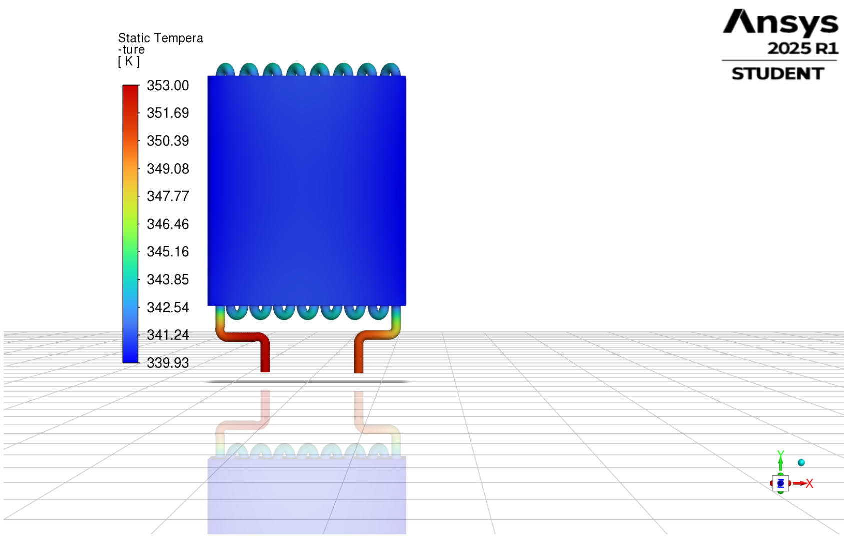

Fig. 9. Ethylene-glycol velocity inlet 0,5 m/s

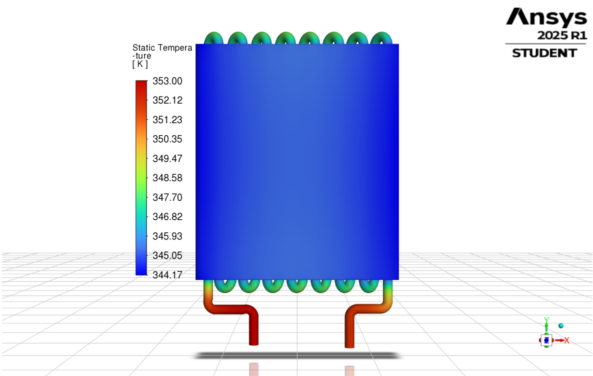

Fig. 10. Ethylene-glycol velocity inlet 1 m/s

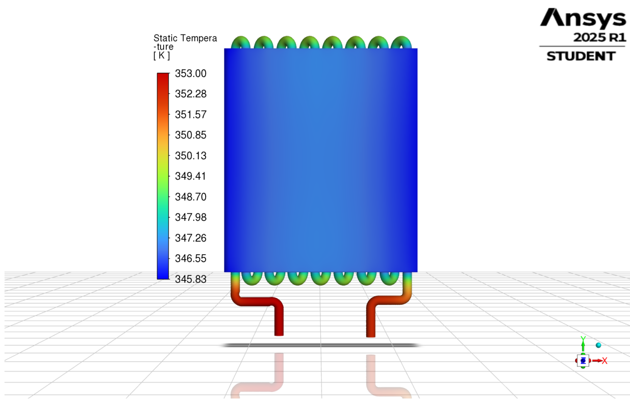

Fig. 11. Ethylene-glycol velocity inlet 1,5 m/s

At **0.5 m/s**, the coolant moves slowly through the radiator channels, which increases the **residence time** and allows more efficient heat transfer from the fluid to the surroundings. This results in a significant temperature drop, with outlet temperatures reaching as low as approximately **339.93 K**, indicating excellent cooling performance. However, the downside of this slower velocity is reduced coolant circulation rate, which may not be optimal in high-load engine conditions where faster cooling cycles are needed.

At **1.0 m/s**, the coolant flows at a moderate speed, reducing the residence time slightly. Consequently, the outlet temperature is somewhat higher than 0.5 m/s, but still within an effective cooling range. This velocity balances cooling efficiency and coolant throughput, offering a practical solution for average operating conditions. The total heat the system removes may increase despite the smaller temperature drop per fluid unit.

The coolant travels quickly through the radiator at a speed of 1.5 m/s, reducing thermal interaction with the tube walls. As a result, the outlet temperature increases further, with less heat transferred per pass. Nonetheless, the **mass flow rate** of the coolant increases, which can enhance the overall heat removal rate if the system is designed to accommodate higher fluid velocities. This is especially relevant in performance or high-temperature environments where rapid heat extraction is more critical than per-pass efficiency [20].

3.4 Percentage of Coolant Temperature Reduction in an Automobile Radiator at Various Flow Velocities and Coolant Types (CFD Simulation Results)

The CFD simulation results revealed a distinct relationship between coolant type, flow velocity, and heat dissipation performance within the automobile radiator system. Table 5 presents the outlet temperatures and corresponding percentage reductions for water liquid, ethylene glycol, and liquid hydrogen at flow velocities of 0.5 m/s, 1.0 m/s, and 1.5 m/s, with a constant inlet temperature of 353 K. At a flow velocity of 0.5 m/s, liquid hydrogen demonstrated the highest temperature drop of 15.84 K (4.49%), followed by ethylene glycol with 13.07 K (3.70%), while water liquid showed the lowest temperature decrease of 3.51 K (0.99%)[21].

Table 5
Outlet temperature and percentage temperature reduction for each coolant fluid at different flow velocities

Fluid	Velocity (m/s)	Inlet Temp (K)	Outlet Temp (K)	ΔT (K)	Dropped (%)
Water liquid	0.5	353	349.49	3.51	**0.99%**
Water liquid	1.0	353	350.15	2.85	0.81%
Water liquid	1.5	353	350.43	2.57	0.73%
Hydrogen liquid	0.5	353	337.16	15.84	**4.49%**
Hydrogen liquid	1.0	353	342.89	10.11	2.86%
Hydrogen liquid	1.5	353	345.26	7.74	2.19%
Ethylene-glycol	0.5	353	339.93	13.07	**3.70%**
Ethylene-glycol	1.0	353	344.17	8.83	2.50%
Ethylene-glycol	1.5	353	345.83	7.17	2.03%

This performance difference is attributed to the thermophysical properties of each fluid, where liquid hydrogen's exceptionally high specific heat capacity and low viscosity promote superior heat absorption per pass. As the coolant velocity increased to 1.0 m/s and 1.5 m/s, the temperature reductions for all fluids decreased due to shorter residence time in the radiator channels, limiting the heat transfer opportunity during each pass. At 1.0 m/s, the percentage drops were 2.86% for liquid hydrogen, 2.50% for ethylene glycol, and 0.81% for water, and further declined at 1.5 m/s to 2.19%, 2.03%, and 0.73%, respectively. Despite the reduced per-pass efficiency at higher velocities, fluids with higher thermal properties, mainly liquid hydrogen and ethylene glycol, performed better than water across all velocities. This trend confirms the expected thermodynamic behavior, where increased velocity leads to diminished heat exchange per cycle but can improve total heat removal over time due to greater mass flow. These findings emphasize the significance of selecting appropriate coolant fluids and controlling flow velocity to optimize automotive radiator performance under different operating conditions, with liquid hydrogen offering the highest potential efficiency, followed by ethylene glycol. At the same time, water remains a standard but less practical choice for high-performance cooling demands[22].

4. Conclusions

A comprehensive CFD-based analysis was conducted to evaluate the thermal performance of an automobile radiator using three different coolant fluids: water, ethylene glycol, and liquid hydrogen, under varying inlet flow velocities of **0.5 m/s, 1.0 m/s, and 1.5 m/s**, with a constant inlet temperature of **353 K**. The simulation aimed to assess the influence of both coolant type and coolant velocity on heat dissipation characteristics, outlet temperature, and per-pass cooling efficiency[9].

The results demonstrated that both **coolant type and flow velocity significantly affect the heat transfer performance within the radiator system**. Among the tested fluids, **liquid hydrogen consistently exhibited the highest percentage of temperature reduction at all velocities**. This superior performance is primarily due to its **exceptionally high specific heat capacity (9772.2 J/kg·K)** and **low dynamic viscosity (0.00001332 kg/m·s)**, which enable efficient thermal absorption with minimal flow resistance. At a velocity of 0.5 m/s, liquid hydrogen achieved a temperature reduction of **4.49%**, outperforming ethylene glycol (**3.70%**) and water (**0.99%**).

Ethylene glycol provided better cooling performance than water across all flow velocities, benefiting from its higher density and favorable heat capacity. However, its thermal conductivity is lower than that of water. It performed exceptionally well at lower velocities, where longer residence times allowed more effective heat transfer per circulation pass. Conversely, **water and liquid, while the most conventional coolants, recorded the lowest temperature drop percentages**. However, it maintained **stable, predictable, and reliable thermal behavior** throughout all tested conditions, reaffirming its suitability for standard automotive cooling systems with moderate thermal loads[21].

A consistent trend was observed across all fluids: **increasing the coolant velocity led to a decrease in per-pass temperature reduction percentage**. This phenomenon is attributed to the **reduction in residence time within the radiator channels at higher velocities**, which limits the opportunity for effective heat exchange per pass. For example, liquid hydrogen's temperature drop percentage declined from **4.49% at 0.5 m/s to 2.19% at 1.5 m/s**. However, **higher velocities increase the mass flow rate**, **potentially enhancing the total heat removal rate over time**, even though the temperature drop per pass is reduced. This trade-off reflects a well-established thermodynamic principle, confirming that while **per-pass efficiency is highest at low velocities**, total system heat removal can be optimized at higher flow rates under continuous operation.

This study confirms that **coolant fluid selection and flow velocity optimization are crucial factors in improving automotive radiator thermal performance**. **Liquid hydrogen offers the highest cooling potential**, although its practical application is constrained by operational and safety concerns associated with cryogenic fluids. **Ethylene glycol emerges as a balanced and reliable alternative**, offering superior cooling capability compared to water, particularly under demanding thermal conditions. **Water remains the safest, most available, and conventional option**, appropriate for typical automotive use where extreme cooling demands are absent.

These findings provide valuable insights for radiator design and operation strategies, emphasizing the importance of matching coolant properties and flow conditions to the specific thermal requirements of modern automotive systems. Future work could extend this investigation by exploring nanofluid-enhanced coolants, varying heat flux levels, and transient operating conditions to optimize radiator performance in conventional and high-performance vehicles [21].

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