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# Experimental study of the application of air-water two-phase in peltier based cooling systems

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## Abstract

In recent years, peltier-based cooling systems have been extensively developed in the automotive sector. However, these systems have primarily focused on single-phase fluid flow, utilizing either liquid or gas, while two-phase flow applications have predominantly been explored in industrial heat exchangers. This study aims to investigate the impact of two-phase air-water flow on the performance of peltier-based cooling systems. The research employed an experimental approach, maintaining a constant superficial water velocity of 0.19 m/s, while varying the superficial air velocity at 0 m/s, 3.7 m/s, 7.5 m/s, 11.7 m/s, 15.6 m/s, and 19.5 m/s. Additionally, three different waterblock designs were tested to evaluate their effectiveness in lowering the temperature of the peltier-based cooling system. Visual observations were conducted to identify the flow patterns formed under different combinations of superficial air and water velocities. The experimental results provided data on flow patterns (e.g., no flow patterns, roll waves, pseudo slugs, and entrained droplets), liquid film thickness, temperature reduction for each velocity variation, and the minimum temperature achieved across the three waterblock models. Statistical analysis using multiple linear regression revealed that superficial water velocity had no significant influence, whereas superficial air velocity demonstrated a significant effect. Furthermore, a one-way ANOVA test confirmed a statistically significant difference in the minimum temperatures achieved by the three waterblock designs.

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## Keywords

Two-phase flow, Peltier cooling system, Heat transfer enhancement

## Introduction

Technological advances in the automotive sector are developing very rapidly and encourage people to always study science and technology, in a vehicle there are components that have major problems in temperature regulation, if this problem is not anticipated properly, it can cause overheating in these components, to overcome this problem every vehicle has a cooling system that has a crucial role in the vehicle. In its development, thermoelectric cooling (TEC) has been studied and used in various fields for electronic cooling, cooling, and battery cooling applications [1]. Thermoelectric modules or often referred to as Peltier elements, are devices that function as heat pumps. The operation relies on the principles of the Peltier effect. The Peltier Effect is the event of heat transfer from the junction of two different types of metals when an electric current flows. When an electric current flows through the junction formed by two types of metals, A and B, heat will be generated at the top of the junction (T2 or Heat Side), while heat will be absorbed at the bottom of the junction (T1 or Cooling Side). The term "PELTIER" was given in honor of the French physicist Jean Charles Peltier, who discovered it in 1834 [2]. The use of Thermo Electric Cooling (TEC) modules or often called Peltier modules as a cooling system is considered an environmentally friendly and reliable cooling method [3]. In the automotive sector, the use of thermoelectric (TEC) modules has been widely developed by researchers. As in the research of [4] who designed a battery cooling package including thermoelectric cooling (TEC) combined with fluid circulation. [5] developed an electric motor battery cooler using Peltier and a fan as additional cooling. [6] developed a vehicle drum brake cooler consisting of a thermoelectric cooling chip (TEC) and a heat exchange system. [7] created a thermoelectric-based car cabin cooling system using 2 TECs with added heatsinks and fans to maximize cooling.

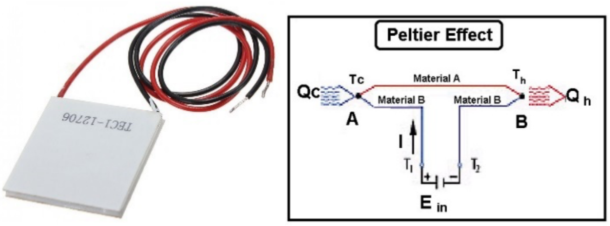


Figure 1. Peltier and how it works

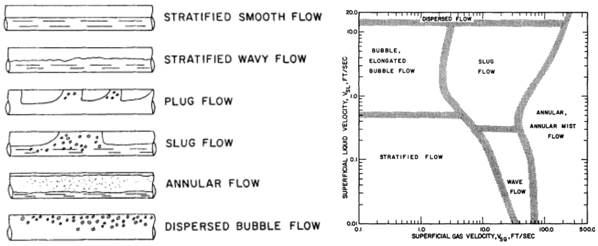


Figure 2. Two phase flow pattern mapping

Meanwhile, several studies on heat exchangers or heat exchangers have developed the use of two-phase flow (liquid-gas), [8] conducted a study on increasing heat transfer in heat exchangers by injecting bubbles into the working fluid so that it forms a fluid flow pattern and can increase heat transfer by 66%. Two-phase flow has different characteristics from one phase. The flow that flows simultaneously in a pipe shows variations in the shape of the interface of the two phases which is called the flow pattern. Knowledge of flow patterns is very important, by understanding the flow pattern it can be used as a reference for choosing a model or correlation to predict fluid flow behavior. The flow pattern is affected by several factors, such as the pipe's position and geometry, flow velocity, and the properties of each fluid. It is defined that superficial velocity is the ratio of volumetric flow behavior to the total area of the flow. In two-phase flow in opposite directions there are two superficial velocities, namely the superficial gas velocity (J_G) and superficial liquid velocity (J_L) are expressed in the following equation.

$$J_G = \frac{Q_G}{A} \quad (1)$$

$$J_L = \frac{Q_L}{A} \quad (2)$$

# Method

## *Experimental Instrument*

This experiment was conducted at the Automotive Safety Laboratory, Road Transportation Safety Polytechnic, Indonesia. In this experiment using a series of cooling systems with the following components (peltier, waterblock, water pump, compressor, radiator, water reservoir, water flow, air flow, and acrylic pipe). Peltier functions as a cooler and an object to be observed, the waterblock functions as a place to transfer heat from the hot side of the peltier to the cooling system channel, the water pump functions to pump water in the circuit, the compressor is used to circulate air in the circuit, the radiator functions to cool the fluid that carries heat from the waterblock, the water reservoir functions to store water, the water flow functions to regulate the flow of water in the circuit, the air flow is used to regulate the flow of air in the circuit and makes it easier to vary the superficial speed of air, the acrylic pipe not only serves as a conduit for flow but also functions as a medium for visually observing the two-phase flow patterns within the cooling system circuit.

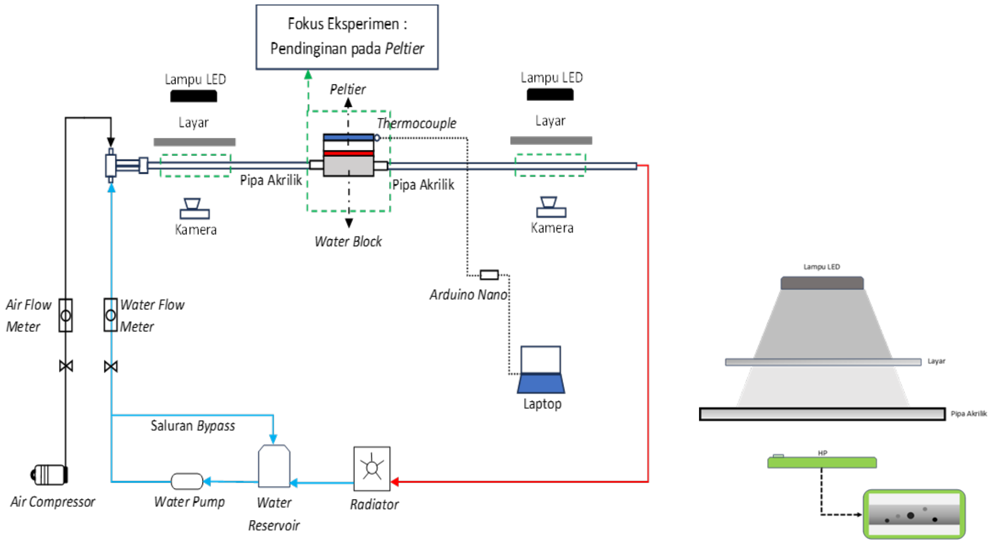


Figure 3. Experimental Schema

As seen in the Figure 3, the experiment was conducted by setting the superficial water velocity at 0.19 m/s, and the superficial air velocity was varied at 0 m/s, 3.9 m/s, 7.8 m/s, 11.7 m/s, 15.6 m/s, and 19.5 m/s. to observe temperature changes in the peltier, a thermocouple sensor was used which was connected to the Arduino Nano microcontroller, then the data was stored in MS Excel. To observe the flow patterns that occur due to variations in the superficial water and air velocity, a camera with a specification of 60 fps was used and assisted by LED lighting from the back of the acrylic pipe to obtain good visual data. The experimental scheme can be seen in the picture. The data collection was carried out on each waterblock model, where in this experiment 3 waterblock models were used as shown in the Figure 4.

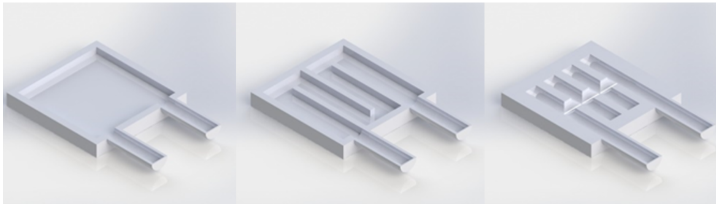

Figure 4. Waterblock Channel Variations

### *Data processing*

In this experiment, two main data will be obtained, namely temperature drop data on the peltier module and visual data on the two-phase fluid flow pattern, from the results of the temperature drop data on the peltier module, it can be analyzed whether the variation in superficial air velocity affects the temperature drop using a linear regression test, for visual data on the flow pattern will be processed using the image processing method, in image processing, mathlab software is used as follows (image loading, image rotation and cropping, image complement, background subtraction, filtering, liquid film thickness detection) from the results of image processing, liquid thickness data is obtained and continued to identify the flow patterns that occur in each variation of superficial air velocity. To determine the effect of the flow pattern on the decrease in temperature of the peltier module, the kruskal wallis test is used. Then the games howell test is used to determine how the difference in cooling temperature drops in 3 different waterblock models.

## Results and Discussion

### *Experimental Results*

From the variation of superficial air velocity (0 m/s, 3.9 m/s, 7.8 m/s, 11.7 m/s, 15.6 m/s, and 19.5 m/s) and constant superficial water velocity at 0.19 m/s, four two-phase fluid flow patterns were obtained (without flow patterns, roll wave, pseudo slug, entrained droplet). Where at a superficial air velocity of 0 m/s the flow pattern formed is without a flow pattern, when the air flow is inserted into the cooling system circuit, an interfacial interaction between the liquid and gas fluids begins, at superficial air velocities of 3.9 m/s and 7.8 m/s the flow pattern that occurs is a roll wave, and at superficial air velocities of 11.7 m/s and 15.6 m/s the flow pattern formed is a pseudo slug, at the highest superficial velocity of 19.5 m/s an entrained droplet flow pattern is formed, where the minimum temperature in each waterblock model experiment is achieved when the entrained droplet flow pattern.

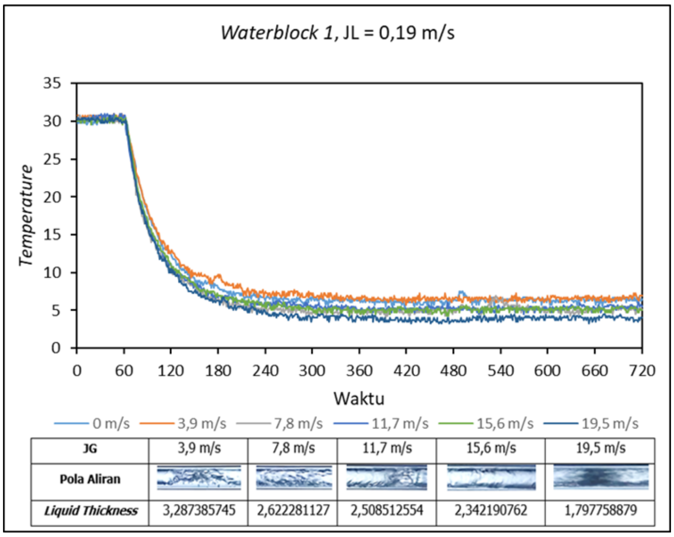


Figure 5. Waterblock experiment graph 1

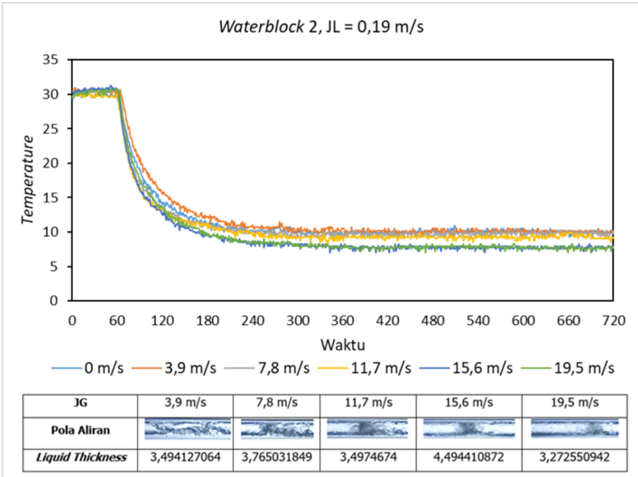


Figure 6. Waterblock experiment graph 2

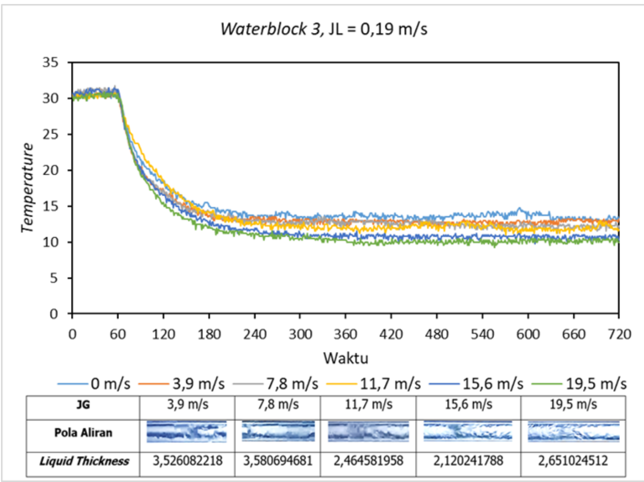


Figure 7. Waterblock experiment graph 3

It can be seen in the graph showing where increasing the superficial air velocity is able to reduce the cooling temperature in the cooling system, where experiments conducted on three types of waterblocks show that the temperature that can be achieved by each waterblock model occurs at the highest superficial velocity of 19.5 ms. in waterblock model 1 the minimum temperature that can be achieved is 3.25 C, in waterblock model 2 the minimum temperature that can be achieved is 7 C, and in waterblock model 3 the minimum temperature that can be achieved is 9.23 C. from these results also show that waterblock model 1 is able to work better than waterblock models 2 and 3, this happens because waterblock model 1 does not have a groove on the inside which causes the heat transfer area from the hot side of the peltier to the waterblock to be wider, so that the heat absorbed by the waterblock can be carried out more by the cooling fluid to be cooled in the radiator.

### *Test Result*

From the results of the Kruskal Wallis test that has been carried out, the asymp value of Sig is more than 0.05, which indicates that the flow pattern formed in this experiment does not have a significant effect on the temperature drop. In this experiment, a multiple linear regression test was also carried out to determine how the effect of superficial air velocity on the decrease in the temperature of the cooling system, where the results showed a Sig value of variable X2 (superficial air velocity) of 0.025 (<0.05) which means that the superficial air velocity has a significant effect on the decrease in the temperature of the cooling system. The Games Howell test was also carried out to determine whether there was a significant difference between the three waternlock models on the minimum temperature achieved by the cooling system, where the results showed a Sig value <0.001 which means that there was a significant difference between the three waterblock models on the minimum temperature that could be achieved by the cooling system, where waterblock model 1 (without grooves) showed the ability to achieve a better minimum temperature compared to waterblock models 2 and 3.

## Conclusion

Based on the experiments and data analysis conducted, the observed flow patterns included No Flow Pattern, Roll Wave, Pseudo Slug, and Entrained Droplet. Among these, the Entrained Droplet flow pattern corresponded to the lowest minimum temperature achieved by the Peltier-based cooling system. However, the flow patterns did not exhibit a significant influence on the minimum temperature obtained. The findings indicate that the superficial velocity of water had minimal impact on temperature variations within the Peltier-based cooling system, whereas the superficial velocity of air significantly affected temperature changes. Furthermore, there was no combined effect of water and air superficial velocities on temperature changes. The results also demonstrated that lower superficial velocities of both water and air led to lower temperatures produced by the system. Additionally, significant differences in the minimum temperatures achieved were observed across the three waterblock models tested. Waterblock model 1 (without grooves) achieved a lower minimum temperature compared to models 2 and 3.

## Acknowledgments

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