Corrigendum: Effect of thermoelectric placement on the commercial waterblock to the liquid cooling system performance (2021 J. Phys.: Conf. Ser. 1763 012039)

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Description of corrigendum:

Page 1:
In the Introduction section line 13-15, the following text appears:

“Azimi et al. [8] use the water is cooled by passing through a block which is on contact with the cold side of a thermoelectric in the liquid cooling garment, showed that temperature difference versus the number of fins and the block dimensions has increasing behavior.”

This should read:

“Azimi et al. [7] use the water is cooled by passing through a block which is on contact with the cold side of a thermoelectric in the liquid cooling garment, showed that temperature difference versus the number of fins and the block dimensions has increasing behavior.”

Page 3:
In the sub section 2.2, the following text appears:

“The performance of thermoelectric modules known from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because of the thermal conductivity of the thermoelectric material, and a portion of the total Joule heating effect generated by the electric current to thermal resistance. From the energy equilibrium is obtained.”

This should read:

“The performance of thermoelectric modules known from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because of the thermal conductivity of the thermoelectric material, and a portion of the total Joule heating effect generated by the electric current to thermal resistance. From the energy equilibrium is obtained [10].”
Page 4:
In the Figure 3, the following figure appears:

![Figure 3](image)

**Figure 3.** Water-cooled temperature Vs time

This should be appeared:

![Figure 3](image)

**Figure 3.** Water-cooled temperature Vs time
The following figures (Figure 4, Figure 5 and Figure 6) appear:

![Figure 4. Qc Vs time](image1)

![Figure 5. Electric current vs time](image2)

![Figure 6. Average COP systems at variation position](image3)
This should be appeared:

**Figure 4.** Qe Vs time

**Figure 5.** Electric current vs time

**Figure 6.** Average COP systems at variation position
Page 6:
In the second line of the first paragraph, the following text appears:

“Observations through CFD were compared with experimental data to validate the simulation results. The simulation uses standard \( k-\varepsilon \) model turbulence, and boundary condition parameters are referred to the observed data.”

This should read:

"Observations through CFD were compared with experimental data to validate the simulation results. The simulation uses standard \( k-\varepsilon \) model turbulence, and boundary condition parameters are referred to the observed data."
Effect of thermoelectric placement on the commercial waterblock to the liquid cooling system performance

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Abstract. Thermoelectric liquid cooling systems have been widely used to maintain the temperature of electronic devices due to their small size, compactness, and simplicity. A few of these cooling systems utilize the waterblock as a liquid heat exchanger. This study aims to determine the performance of a thermoelectric-based water cooling system in a commercial waterblock. The research was conducted in the laboratory using a 4x12 cm aluminium waterblock placed on the cold side of TEC1-12715. Three variations of thermoelectric placement have been carried out: at the inlet and outlet, in the middle, and the end of the waterblock. The temperature of the coolant and the flow rate of the cooled fluid are kept constant for these variations. The results showed that the thermoelectric position on the waterblock affected the rate of reduction in fluid temperature and the cooling system's performance.

1. Introduction

Electronic devices' increasing function in modern devices results in an increase of power dissipation and heat sources in electrical components requiring an efficient cooling system to keep the performance of these components' abilities. The thermoelectric cooler (TEC) based liquid cooling system is an attractive choice because it has many advantages, including small, portable, quiet, and environmentally friendly. Kang et al. [1] describe the design and attributes of a sophisticated liquid cooling system that can cool one or more heat sources in a computer system. Surve and Hatte [2] analyzed the CPU cooling systems using a liquid with different heat sink types with different geometries. Khonsue [3] studied experimentally on a thermoelectric liquid cooling system for personal computers. Hahm and Park [4] conducted an experimental study on an electric component liquid cooling system's performance with variations in the water block's internal shapes. Jin Tae Choi et al. [5] worked with the numerical study of the heat transfer and fluid flow of the micro-channel water block for computer CPU cooling. Al Rubaye et al. [6] focus on the thermal performance experimental study of portable thermoelectric water cooling systems. Azimi et al. [8] use the water is cooled by passing through a block which is in contact with the cold side of a thermoelectric in the liquid cooling garment, showed that temperature difference versus the number of fins and the block dimensions has increasing behavior. The liquid closed-loop cooling system with Integrated Mini-Channel Heat Sink has been implemented by Ma et al. [8], which results in a high and reliable thermal performance using the heat sink with corrugated fins. Kuznetsov et al. [9] studied a turning tool equipped with an internal liquid cooling closed-loop. The cross-sectional area is one of the factors that affect the rate of heat transfer, this research was carried out to observe the application of larger waterblock compare to TEC dimensions and focus on the effect of TEC placement on the waterblock to the performance of the water cooling system.
2. Materials and methods
This research was carried out through experimental methods and CFD simulations using two commercial aluminium waterblocks, a 4x4 cm waterblock placed on the hot side, and a 4x12 cm waterblock placed on the cold side TEC1-12715. The inside of the waterblock contains 12 rows of 1 mm thick aluminium fins with the same distance as the 1 mm thick plate, which divides the waterblock space into two spaces for fluid flow in and out (Figure 1).

![Figure 1. Aluminium waterblock 4×12 cm.](image)

2.1. Experimental setup
Coolant was circulated from the water batch with a constant flow rate and temperature of 4 l/min and 30°C to 4x4 cm waterblock, on the hot side of TEC. One litre of water as the heat load placed in the container and circulated to 4x12 cm waterblock on the cold side of TEC through DC pump with a constant flow rate of 2 l/min for each variation positions. The water storage container and thermal insulator of the TEC liquid system are made of styrofoam to minimize the external heat infiltration. The temperature of ambient for all variation experiments was maintained on 30°C. Digital thermometer with data logger used to measure and record temperature changes on the water temperature in the water box (T_w), coolant temperature, cold and hot side temperature of the TEC (T_c and T_h), the inlet-outlet water temperature (T_{in}) (T_{out}), waterblock surface temperature at in-out (T_1), the middle (T_2) and the end (T_3) section, the ambient temperature, and the water batch. The input current and voltage of TEC are measured by using a dual digital volt-ampere meter. All data recorded every minute for 90 minutes on each test variation. The testing is done repeatedly three times on each variation to validate the experimental data. The study is also carried out through the Computational Fluid Dynamic (CFD) using Solidworks student edition software as a comparison and complement.
2.2. Calculation and data analysis

The performance of thermoelectric modules known from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because of the thermal conductivity of the thermoelectric material, and a portion of the total Joule heating effect generated by the electric current to thermal resistance. From the energy equilibrium is obtained:

Seebeck Coefficient:

\[
\alpha = 2 \cdot \alpha_m \cdot N
\]  
(1)

Seebeck coefficient of the device (V/K):

\[
\alpha_m = \alpha_0 + \alpha_1 \cdot T_{ave} + \alpha_2 \cdot T_{ave}^2
\]  
(2)

Thermal conductivity

\[
K = 2 \cdot K_m \cdot N \cdot G
\]  
(3)

Device thermal conductance

\[
K_m = K_0 + K_1 \cdot T_{ave} + K_2 \cdot T_{ave}^2
\]  
(4)

Device electrical resistance

\[
R = \frac{2 \cdot \rho \cdot N}{G}
\]  
(5)

Resistivity

\[
\rho = \rho_0 + \rho_1 \cdot T_{ave} + \rho_2 \cdot T_{ave}^2
\]  
(6)

Heat Absorbed at the Cold Side of TEC:

\[
\dot{q}_c = 2N \left[ \alpha_m \cdot I \cdot T_c - K_m \cdot \Delta T_p \cdot G - \left( \frac{I^2 \cdot \rho}{2G} \right) \right]
\]  
(7)
Heat dissipated on the hot side of TEC:

$$\dot{q}_h = 2N \left[ \alpha_m \cdot I \cdot T_h - K_m \cdot \Delta T_p \cdot G \left( \frac{I^2 \cdot \rho}{2G} \right) \right]$$  \hspace{1cm} (8)

The input power of TEC:

$$P_{in} = I^2 \cdot R$$  \hspace{1cm} (9)

The figure of merit (Z) is a combination of three parameters on the thermoelectric properties, influences the cooling effect, and indicates the quality of thermoelectric elements.

$$Z = \frac{\alpha_m^2}{\rho \cdot K_m}$$  \hspace{1cm} (11)

The efficiency of a thermoelectric cooling system obtained from a comparison of the amount of heat absorbed at the cold side to the input power:

$$COP = \frac{\dot{q}_c}{P_{in}}$$  \hspace{1cm} (12)

3. Results and Discussion

The observation results show the difference in water temperature decrease for the three variations of TEC placement. The largest temperature drop is in the TEC placement in the waterblock's middle position, as shown in Figure 3.

The heat absorption on the cold side of the TEC is shown in Figure 4. It can be seen that the greatest heat absorption occurs in the initial minutes and then decreases with a decrease in the temperature of the circulating water. However, the lowest heat absorption occurs when the TEC is in the In-Out waterblock position. It occurs due to the release of heat on the TEC's hot side, which is relatively constant due to constant temperature and coolant flow rate. It is followed by a relatively constant change in electric current, as shown in Figure 5. The placement of TEC affects the COP system, where on average, the TEC placement position in the middle of the water block is slightly higher than the other two positions, as shown in Figure 6.
Figure 4. Qc Vs time

Figure 5. Electric current vs time

Figure 6. Average COP systems at variation position
Observations through CFD were compared with experimental data to validate the simulation results. The simulation uses standard k-ε model turbulence, and boundary condition parameters are referred to the observed data. Experimental data are taken from the average data with a standard error of 0.033 to 0.321 for all configurations. The experiment data indicate that the difference in temperature decrease for the three positions starts at the first minute; The comparison of the waterblock surface temperature between simulation and experiment at the first minute as follows:

| TEC Position | Experiment | CFD |
|--------------|------------|-----|
|              | $T_1$ | $T_2$ | $T_3$ | $T_1$ | $T_2$ | $T_3$ |
| In-out       | 25.17 | 30.43 | 30.50 | 24.50 | 29.45 | 29.84 |
| Middle       | 29.37 | 25.40 | 30.07 | 29.02 | 24.82 | 29.23 |
| End          | 31.27 | 31.17 | 25.90 | 30.29 | 29.86 | 25.68 |

The comparison of water temperature data entering and leaving the water block between the experiment and simulation at the first minute can be seen in Table 2 below:

| TEC Position | Water circulation temperature ($^\circ$C) |
|--------------|----------------------------------------|
|              | Eksperimen | CFD |
|              | $T_{in}$ | $T_{out}$ | $T_{in}$ | $T_{out}$ |
| In-out       | 30.26 | 30.00 | 30.26 | 29.64 |
| Middle       | 30.00 | 29.36 | 30.00 | 29.25 |
| End          | 30.56 | 30.26 | 30.56 | 29.97 |

**Figure 7.** Waterblock surface temperature at variation of TEC position
The difference between the experimental and simulation results below 10% can be used as an approximation. The temperature distribution on the waterblock surface at each TEC position is shown in Figure 7. It shows that TEC's placement on the middle surface produces a low-temperature area, relatively wider than at the in-out position and the end position. Figure 7a, shows the temperature inlet fluid spread over the entire surface of the waterblock section and creeping into the water block outlet. For TEC at the in-out placement, the high-temperature distribution is at the end section of the water block. For the TEC position in the middle of the waterblock, figure 7c., the low temperature distribution is quite wide, which indicates that at that position, heat can be absorbed properly.

The fluid temperature distribution in the middle of the waterblock space in Figure 8, indicate that the lowest fluid temperature occurs around in the waterblock room divider. The low fluid temperature when exiting the waterblock is more at the placement of TEC in the middle of the waterblock than the other two positions.

![Figure 8. Distribution of water temperature in the middle space of waterblock](image)

Figure 8. Distribution of water temperature in the middle space of waterblock

The flow rate pattern of cooled water in the center of the waterblock room is shown in Figure 9, the highest water velocity occurs at the inlet-outlet channel and in the narrow gap at the end of the waterblock. Inlet and outlet channel position, which is close to the outer side induces the outside flow along the waterblock chamber was higher than in the middle space. The fluid flow velocity affects the heat transfer rate [11], heat transfer increases when velocity decreases because the heat has enough time
to transfer from water to the block and results in a significant release of heat from the water [7]. Therefore, the TEC position in the middle of the waterblock surface results in a lower water temperature than the other two placements. To ensure that the TEC position affects the TEC performance, simulations using CFD are also carried out under uniform boundary conditions in the first minute conditions, as shown in Table 3.

Table 3. Temperature of cooled water at uniform boundary condition

| TEC Position | Water circulation temperature (°C) |
|--------------|-----------------------------------|
|              | \( \text{\text{In}} \) | \( \text{\text{Out}} \) |
| In-out       | 30.6                              | 30.07               |
| Middle       | 30.6                              | 29.86               |
| End          | 30.6                              | 30.01               |

The temperature distribution of the cooled water in the center of the water block chamber with uniform boundary conditions as in Figure 10. It shows that the highest water temperature drop occurs at the TEC position in the middle of the water block compared to the other two placements.

![Temperature distribution](image)

Figure 10. Water temperature distribution in the waterblock chamber

4. Conclusion
The results show that the placement of TEC on the surface of a commercial waterblock affects the fluid heat transfer rate and system performance. The best position is on the middle surface of a commercial waterblock, which results in a wider spread of heat absorption than the other two placements. The mini-channel configuration in the waterblock results in variations of fluid flow rates that affect the fluid heat dissipation rate.

Acknowledgement
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