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Uncovering the Cooling Potential by Water Circulation on the Hot Side of a Peltier Module †

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Abstract: Thermolectric cooling offers several advantages over conventional refrigeration systems due to its light weight, environmental friendliness, silent operation, and no moving parts. In this work, a thermoelectric water cooling system is created in which water flowing at various flowrates removes heat produced on the hot side of the Peltier module. The cooling effect and coefficient of performance (COP) of the cooling system are experimentally determined at various flowrates of water on the hot side of the module. The cooling effect produced in water increases with the increase in flowrate. A similar trend is noticed for the COP of the system. The maximum cooling effect produced in water is 1363 W at 43 mL/s. The maximum COP of the system is 3.99.

Keywords: thermoelectric cooling; Peltier module; cooling effect; coefficient of performance

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1. Introduction

The Peltier effect governs how thermoelectric coolers (TEC) function. According to the Peltier effect, a temperature differential results from applying an electric potential across the junction. The electric current passes across the junctions of the two conductors as a result of the application of voltage. At one connection, heat is emitted, and at another, where cooling takes place, heat is absorbed. When conventional cooling techniques are not appropriate, TEC offers a wide range of advantages. TEC is also more ecologically friendly than other cooling systems on the market. Gökçek et al. [1] investigated the thermoelectric refrigerator's thermal performance using a mini-channel heat sink integrated on the hot side of TEC. The effectiveness of TEC for air heating and cooling applications was investigated experimentally and numerically at various fan speeds and operating voltages by Yilmazoglu et al. [2]. Cosnier et al. [3] worked to develop the thermoelectric cooling and heating system for indoor use. The performance of the system was experimentally tested, and results were validated through a numerical study. Gull et al. [4] developed a thermoelectric cooling module via a combined series and the parallel connection of Peltier modules. The module was numerically simulated, and the results were validated with experimental findings. Siahmargoi et al. [5] proposed a mathematical and thermodynamic model to investigate the performance of TEC. The effect of changing the voltage and the thermal resistance of cold and hot side heat sink on the performance of a TEC was tested. In the present study, a thermoelectric system is developed for water-cooling purposes, and the effect of varying flowrate on the cooling effect of water is investigated.

2. Methodology

Heat is absorbed at the cold-side junction and released at the hot-side junction when the DC current is transmitted through the thermocouples of the Peltier module. The methodology involves cooling the water using the Peltier module. The biggest issue is that if the Peltier module becomes too hot, it could become damaged. When the heat produced on the hot side of the Peltier module is effectively removed, the thermoelectric modules operate at their best. The issue of overheating can be overcome using heat sinks. In this study, a water block was placed on the hot side of the Peltier module, and generated heat was removed via different flowrates of water.

2.1. Experimental Setup

The experimental setup is shown in Figure 1. The Peltier module used in the experimentation is TEC1-12706, which is operated by a 12 V power supply. The water to be cooled down is kept in a small water tank that is mounted on the cold side of the Peltier module, and the water flowing via a water block dissipates the heat produced on the hot side of the Peltier module. The water block is of 40 × 40 mm^2 cross-section attached by thermal paste on the hot side of the module. A 12 V water pump was placed inside a tub full of water to ensure the flow of water through a pipe. Water flows through pipes and passes through water blocks attached to remove the heat. A flow meter was attached at the end of the pipe and connected through a computer initially to check the flowrate using an Arduino code. A waterproof temperature sensor LM35 was used to determine a change in the temperature of the water that passes through the water block and in a water tank on the top of the Peltier module with the help of an Arduino code and PC setup.

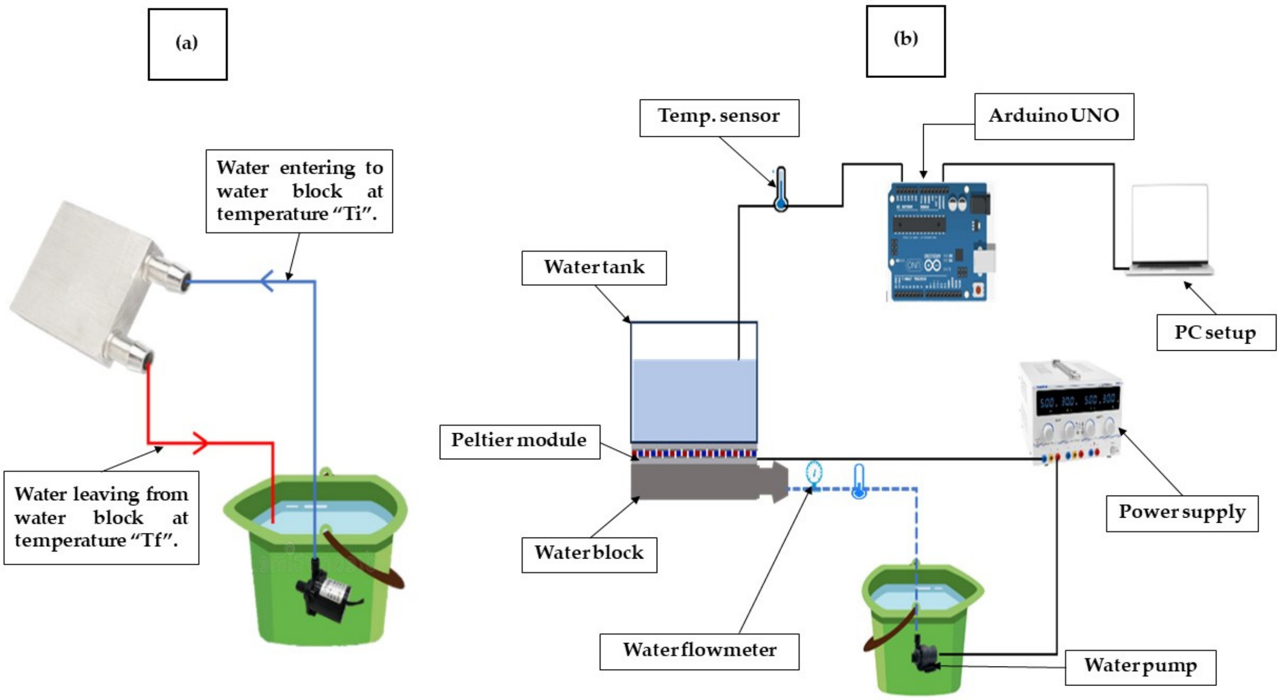

Figure 1. (**a**) Water flow path from water block to water bucket. (**b**) Schematic of experimental setup.

2.2. Performance Parameters

A flow sensor and flow control valve are used to measure and control the flow of water. The temperature of the water can be measured by the LM35 sensor. A mass flowrate of water can be determined using Equation (1),

$$\dot{m} = \dot{V} \times \rho \tag{1}$$

The cooling effect in the present study has been computed using the rate of heat transfer of the cold side by assuming an energy balance between the hot and cold sides of the fluid.

$$\text{Heat transfer rate} = \dot{m}C_p\Delta T \tag{2}$$

The coefficient of performance (COP) of this water-cooling system can be measured by the following relation,

$$\text{COP} = \frac{\text{Heat trasnfer rate}}{\text{Peltier power} + \text{pump power}} \tag{3}$$

Here, the mass flowrate of flowing water through the water block is shown by $\dot{m}$ and $\dot{V}$ is the volumetric flowrate, ρ is the density of the water, C_p is the specific heat at constant pressure, and ΔT is the difference between T_i and T_f. T_i is the temperature of the water before entering the water block, and T_f is the temperature of the water leaving the water block after absorbing the heat.

3. Results and Discussion

The experiments were carried out to determine the effect of varying flowrates of water flowing on the hot side of the module through the water block. Three flowrates of water, 7.5 mL/s, 20.1 mL/s and 43 mL/s, were selected to test the cooling effect, COP, and temperature difference of this water-cooling system. Temperature was directly measured via the temperature sensor. Equations (2) and (3) can be used to determine the cooling effect and COP of the system, respectively. The measured temperature of the water, cooling effect, and COP of the system are shown in Table 1.

Table 1. Experimental results at different flowrates.

Sr. No.	Volumetric Flowrate (ml/s)	Initial Water Temperature (°C)	Final Water Temperature (°C)	Rate of Heat Transfer (W)	Peltier Power (W)	Pump Power (W)	COP
1	7.5	27.82	24.40	226	92	0.9	2.72
2	20.1	27.82	24.97	635	92	1.96	3.94
3	43.0	27.82	25.10	1360	92	3.52	3.99

Figure 2a shows the variation in the cooling effect of the system by varying the flowrate. Equation (2) is used for the calculation of the cooling effect. The effect of flowrate on cooling effect is noticed for three different values of flowrate and linear relation is obtained between them. By increasing the flowrate of water, the cooling effect produced can also be increased. The maximum value of the cooling effect obtained is 1360 W, which is at 43 mL/s. Initially, water to be cooled is at 27.82 °C and at a flowrate of 7.5 mL/s, water temperature decreases to 24.40 °C. At 20.1 mL/s, the temperature difference between the final water temperature and initial water temperature before operating the cooling system decreases to 2.85 °C. Similarly, at 43 mL/s, this temperature difference is 2.72 °C.

Figure 2b shows the variation in COP of the system with flowrate. Similar to the cooling effect, there is an increasing trend of COP due to the varying flowrates. At a low flowrate, the change in the value of COP is significant; the reason for this variation is less pumping power at a low flowrate since the COP is the ratio of cooling effect to power input. At higher flowrate values, the pumping power increases, which results in a slight increase in the value of COP. The maximum value of COP is 3.99 at a flowrate of 43 mL/s.

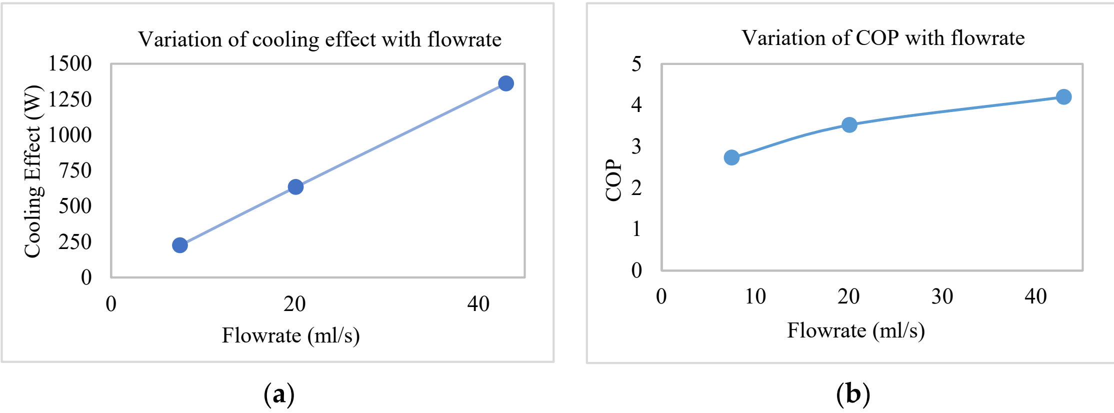

Figure 2. Effect of flowrate on (**a**) cooling effect, and (**b**) COP.

4. Conclusions

In this study, the cooling effect produced in water is investigated, by removing the generated heat on Peltier's hotter side through water flowing at different flowrates. The cooling effect, COP and temperature drop of the water are determined at different flowrates. From the results, by increasing the flowrate of water, there is an increase in the cooling effect produced. Variation in flowrate also shows an increasing trend with COP. It is noticed that at the higher flowrate, there is a slight increase in the COP of the system, due to the increase in pumping power.

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