EXPERIMENTAL INVESTIGATION OF COOLING PERFORMANCE IN ELECTRONIC INSTRUMENTS

by

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This study explores the principle of producing cold through heat absorption at a temperature lower than ambient temperature, which requires the use of an endothermic mechanism. Specifically, the study focuses on evaluating multiple thermoelectric coolers using aluminum water heat exchangers as a means of validating a proposed correlation through a series of experiments. The system utilizes water as a coolant and a thermoelectric cooler coupled with a heatsink to cool it. The cooling power of the system is controlled by adjusting the temperatures of the hot and cold heatsinks and the coolant flow through the heat exchanger based on governing equations. In addition to assessing the cold-side temperature, the research also investigates the system COP of the thermoelectric system. The results indicate that a thermoelectric cooler with a lower thermal resistance is more effective at cooling and can achieve a lower cold-side temperature. Conversely, a cold-side heatsink with a higher thermal resistance provides lower cooling power. Two experiments were conducted to acquire comprehensive data on the thermoelectric devices, and the obtained results and experience were used to categorize the utilization of the Peltier model. The first experiment achieved an 84% success rate, while the second experiment achieved a rate of around 97-95%, highlighting the potential for further experimentation with alternative configurations.

Key words: *aluminum water heat exchangers, effectiveness, efficiency*

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Introduction

The process of cooling a body is achieved by removing heat from it rather than supplying it with cold, as cold is not a physical entity but rather a relative absence of heat [1]. This concept of cooling is achieved through various means, including the use of cooling fans and thermoelectric heat pumps, which are utilized in a wide range of applications, such as cooling radiation sensors, laser thermostats, and climate control systems. In laboratory equipment, Peltier-effect coolers offer several advantages, including the absence of mechanical moving parts, which allows for decades of operation without the need for maintenance [2]. This not only reduces the operational costs but also ensures that the equipment operates reliably and consistently, making them an ideal choice for various cooling applications. Additionally, thermoelectric cooling offers the advantage of precise temperature control, making it particularly useful for applications where temperature stability is critical, such as in scientific experiments and industrial processes. Overall, the use of cooling technology, such as thermoelectric cooling, has become increasingly prevalent in various fields due to its efficiency, reliability, and versatility.

O'Brien *et al*. [3] demonstrated that thermoelectric couplings are feasible to connect thermally and electrically so that the resulting cascade may provide the desired cooling. Silberstein *et al.* [4] demonstrate that precise measurements of transitory thermal effects caused by PID may be made using conventional thermocouples in the Bi/MnBi eutectic during symmetrical solidification. They studied the spatial profile of thermal transistors during Peltier pulsation in the eutectic Bi/MnBi and pure bismuth to get reliable data for such a model. Hava *et al.* [5] presented thermal analysis, namely thermal evaporation and the cooling effect of a monolithic laser structure cooled by the Peltier effect. A Peltier-effect thermoelectric cooling layer was used as an element of the surface layer to obtain thermal assessments and additional cooling (about 2 °C). Sidorenko [6] considered the methods of strengthening the force of Bi-Sb alloys, the best materials of type *n* for cryogenic cooling systems with the Peltier effect. Exemplifications of using Bi-Sb alloys improved mechanically with Bi-Sb-Te alloys and critical-temperature supraconductors in a variety of Peltier cryogenic. Galffy *et al.* [7] presented Peltier effect measurements in mixed Bi, Pb, rzCazCu, and Od states. The BSCO Peltier coefficient increases noticeably in a magnetic field, similar to resistance and thermal power. A comparison with thermal power demonstrates that the Thomson connection is correct. Scherrer *et al.* [8] proposed and described a method of measuring the thermoelectric power of thermoelectric materials over a temperature range of 300 K to 1200 K. The Peltier or Joule effect regulates the temperature using thermoelectric modules. Using a simulation for FEM, Goncalves *et al.* [9] present preliminary results of the first network of micro-cooler thermoelectric on velvet (64 pixels). Using V-VI co-evaporated Bi_2Te_3 and Sb_2Te_3 as thermoelectric substrates, and this micro-refrigerator network can be fabricated using thin-plate technology. Generally, these thin couches had a thermoelectric figure of merit (ZT) close to a unit for *n*-type and 0.6 for *p*-type. Drebushchak [10]. The thermodynamic consideration of thermoelectricity in metals has been applied to the Peltier effect as it has been to the Seebeck effect. The author proposed a model for calculating the Peltier coefficient. In a study conducted by Vian *et al.* [11], a computer model was employed to optimize a thermoelectric ice-maker installed in a non-frost refrigerator. This model was used to determine the electrical consumption of the Peltier module and its ability to generate ice. To achieve maximum ice production, the length of the thermocouples in the Peltier module was optimized. Ari and Kribus [12] have demonstrated that the Peltier effect can contribute to measurable changes in Ge-based

CPV temperature gradients. This effect must be considered in cell simulations. In addition to photovoltaic cells, the effect may also affect other high-power optoelectronic devices. Gupta *et al*. [13] develop a calculation model to analyze the cooling of hot spots on the plate using a Peltier effect ultrafine cooling device. They also investigated the effect of operating modes in both permanent and transitory modes on hot-spot temperature reduction. Garrido *et al*. [14] describe a simple and well-founded experiment for determining the Peltier coefficient in a first-cycle laboratory. Harnsoongnoen *et al*. [15] have described the effects of heating by Joule and Peltier effects in MRAM using a thermoelectric spin transfer coupling (TSTT-MRAM). Simulated aimantation commutation was performed at the magnetic tunnel junction MgO/CoFe. Maruša *et al*. [16] described a new circuit that allows the energy from a Peltier effect system to be recovered using a condenser and a commutation amplifier (SC-BC). According to their analysis and simulations, the SC-BC has proven to be an effective solution for increasing the tension provided by the system to Peltier effect elements. Using the FEM, Rezania *et al*. [17] solved the 3-D equations relating to thermoelectricity and heat transfer. The findings, consistent with earlier calculus studies, demonstrate that the module's maximum energy production and cost-performance result in An/Ap 1 due to the different electrical resistance and thermal conductivity of the materials under consideration. In a study conducted by Kossyvakis *et al*. [18], the performance of a thermoelectric solar conversion unit was analyzed using numerical methods. The researchers evaluated the system's electrical output and predicted its efficiency under various operating conditions. Meng *et al.* [19] created a thermoelectric generator model that utilizes multiphysics principles to recover waste heat from automobile exhaust. Their model incorporates detailed representations of both the exhaust heat source and the water-cooling heat sink. Li *et al.* [20] conducted research into the development of a solar concentrating thermoelectric generator that utilized a micro-channel heat pipe array. Their work involved designing and building a mathematical model to simulate the behavior of the system. The development of an ailette-structured conduit that serves as a room for recovering lost heat and is fixed to the hot TEG sides has been made by Huang *et al.* [21]. The cold TEG sides are connected to a cooling system. The lost heat recovery chamber recovers the energy from the exhaust gas heat that the TEG converts to electricity. In order to represent the structural form profiles and ensure that the optimized configurations have clear structural bounds, Furuta *et al.* [22] suggest a topology optimization method that is particularly suitable for the design of thermoelectric actuators. The development of segmented thermoelectric generators, whose plates P and N are made up of several thermoelectric material segments joined in series, was made to enhance the capabilities of thermoelectric generators [23]. A modeling technique and economic model have been developed for a floating photovoltaic PV-batteries system feeding a submerged LED lighting system [24]. The system was created to provide roughly the same amount of light (1000 lm) as the existing light-based fishing technology (a floating kerosene lamp) [25] for artisanal light-based fishermen to use for eight hours each night on the Lac Victoria and other nearby lakes (Tanganyika, Rukwa, Mweru, Kivu, *etc*.).

This study focuses on developing an experimental process for the collection of thermoelectric energy, which is increasingly important given the growing demand for more efficient energy harvesting methods. The development of new thermoelectric materials and devices, such as thermoelectric generators (TEG), has led to the need for more effective methods of energy collection. The TEG are particularly useful for harvesting waste heat in micro-scale applications and have potential applications in various fields, including clinical devices, sensors, structures, and consumer electronics. One area where TEG have proven especially effective is in conjunction with cooling fluids. When used in cooling systems, thermoelectricity can increase efficiency and provide a more sustainable means of energy generation. By harnessing the temperature difference between a cooling fluid and the surrounding environment, TEG can convert waste heat into usable energy, reducing energy waste and lowering overall energy costs. The experimental process developed in this study can help improve the efficiency of TEG and enable their wider adoption in a range of applications. By providing a more efficient means of energy harvesting, TEG can contribute to the development of more sustainable and environmentally friendly energy systems. The insights gained from this study can inform the design and optimization of future TEG and advance the development of more efficient and sustainable energy harvesting technologies.

Mathematical theory

Thermoelectricity is a fascinating phenomenon that allows the conversion of heat energy to electrical energy and vice versa. Thermoelectric devices consist of thermoelectric coolers (TEC) and thermoelectric generators. The TEG have shown great potential in waste heat recovery applications, while thermoelectric coolers have become increasingly popular in providing precise temperature control and cooling in a wide range of applications, such as electronic packaging, medical equipment, and even space exploration. In a thermoelectric cooler, an electrical current is passed through a thermoelectric material, resulting in one side of the material becoming cooler and the other side becoming hotter. This creates a temperature difference that is used to cool or heat a device, depending on the direction of the current flow. The use of thermoelectric technology is particularly attractive because it is environmentally friendly, compact, and has no moving parts, making it suitable for long-term operation without maintenance. Thermoelectric coolers, also known as Peltier coolers, utilize the Peltier effect to provide cooling and temperature control. The Peltier effect involves the creation of a temperature difference between two materials when a current flows through their junction. When a DC voltage is applied to the thermoelectric module, it causes an electrical current to flow through the module, which generates a temperature difference between the module's hot and cold surfaces. The temperature difference can be increased or decreased by changing the direction of the current flow. The use of thermoelectric coolers offers several advantages over traditional cooling systems, including their compact size, solid-state nature, and lack of moving parts. A schematic view of an electrical circuit and a thermoelectric cooler is depicted in fig. 1, which illustrates the direction of the electrical current and the resulting T difference between the hot and cold surfaces of the module.

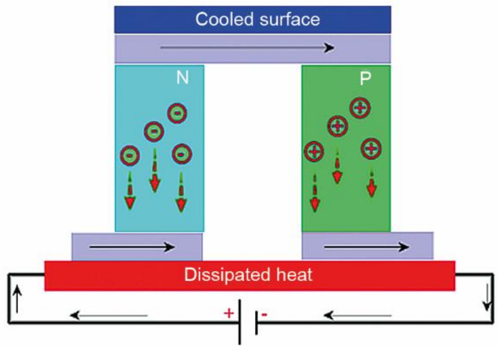

Figure 1. Thermoelectric cooler design

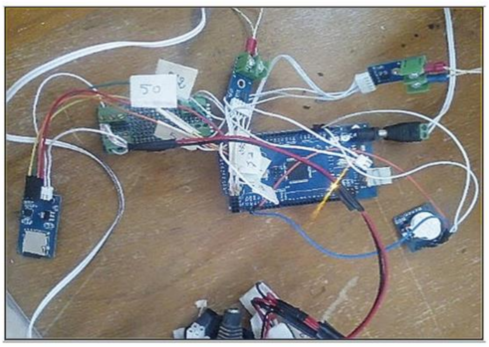

Figure 2. Data acquisition process illustrated

The process of energy transfer is often noted to involve the absorption of heat by the cold side of the thermoelectric module and its subsequent transmission to the hot side for dissipation. The input and output of heat from the different sides of the thermoelectric cooler can be determined using:

$$Q_c = \alpha I T_c - 0.5\beta I^2 - \gamma\Delta T \tag{1}$$

$$Q_h = \alpha I T_h - 0.5\beta I^2 - \gamma\Delta T \tag{2}$$

where $\alpha, \beta, \gamma, I, Q_c, Q_h, T_c, T_h$ and ΔT represent the electrical resistance, thermal conductance, and the Seebeck coefficient. A TEC two sides temperature difference can be stated:

$$\Delta T = T_h - T_c \tag{3}$$

The two sides of a TEC produce their own heat, and the power supplied to it is equivalent to the difference between the heat input and output of each side. The supplied power and voltage can be calculated using the following equations:

$$V = \alpha\Delta T + \beta I \tag{4}$$

$$W = VI \tag{5}$$

where W [W] is the power source and V [V] – the voltage. In a cooling system, the COP is the ratio of cooling power to provided power:

$$COP = \frac{Q_c}{W} \tag{6}$$

Experimental research

To advance our project, we have undertaken experiments aimed at gaining a deeper understanding of the functioning of the Peltier module. Our focus is on exploring the module mechanism of converting electricity into heat and its various applications in our daily lives. Additionally, we aim to delve deeper into the underlying physical phenomenon that makes the Peltier effect possible. By conducting these experiments, we hope to gain valuable insights into the practical applications of thermoelectricity and the potential benefits it holds for the future.

In our experimental set-up, we utilized four Peltier modules, which are compact and versatile devices capable of generating both cooling and electricity. The Peltier effect is a well-known physical phenomenon that occurs when an electric current is passed through a junction of two dissimilar materials, resulting in a temperature difference between the two materials. The Peltier modules we used are designed to exploit this phenomenon, with each module capable of supplying a controlled amount of cooling by removing heat from one side and transferring it to the other. These modules have found applications in various fields, including refrigeration, thermoelectric power generation, and microclimate control in electronic devices, among others.

$$\Pi_{ab} = \frac{P}{I} \tag{7}$$

The equation to calculate the power output of a heat exchanger that has fluid flowing through it is:

$$\Phi_0 = q_{me} C_e \Delta T \tag{8}$$

where Φ_0 is the heat output in watts or joules per second, q_{me} [kgs^{-1}] – the mass-flow rate of the fluid, C_e [Jkg^{-1}K^{-1}] – the specific heat capacity of the fluid, which is the amount of heat energy required to raise the temperature of one kilogram of the fluid by one Kelvin, and ΔT [K] – the temperature difference between the inlet and outlet of the fluid. By using this equation, the power output of a heat exchanger can be calculated accurately.

In its basic form, eq. (8) assumes that the fluid flow through the heat exchanger is steady, and the specific heat capacity of the fluid remains constant. However, in practical situations, the properties of the fluid can vary with changes in temperature and pressure, and the flow rate may not remain constant. These factors can significantly impact the overall heat transfer, and thus must be carefully considered in any real-world application of this equation.

The experimental set-up is illustrated in fig. 2. The system comprises an Arduino microcontroller linked to two *K*-type temperature probes, as depicted in fig. 3. The temperature probes are connected to an analog-to-digital converter, which facilitates the acquisition of temperature readings. It is noteworthy that the use of *K*-type thermocouples provides a reliable and accurate method for temperature measurement. By using an analog-to-digital converter, the temperature readings can be converted into digital signals and processed by the microcontroller.

Figure 3. Aluminum heat exchangers utilized in the experiment

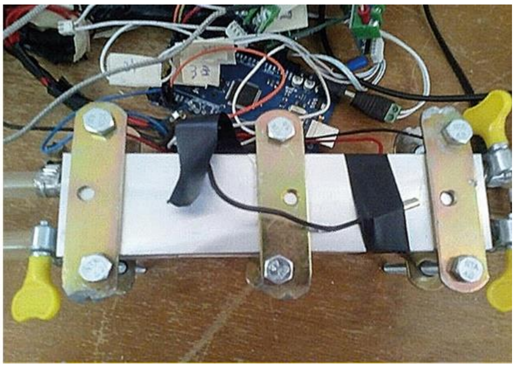

Figure 4. Probe contact with the exchanger surface

The converter plays a crucial role in the process of converting a single probe measurement into a digital value, thereby enabling precise and accurate data acquisition. To ensure reliable time synchronization of the collected data, an RTC is utilized. Furthermore, the Peltier modules, which operate on a 12-volt power supply, are strategically mounted onto the heat exchangers as illustrated in fig. 4. The heat exchangers are interconnected through a tube that enables the circulation of coolant fluid. Two pumps operate in closed circuits, one for cold and the other for hot, facilitating the efficient transfer of heat. The thermoelectric modules are situated between the exchangers. In order to enable the smooth functioning of the water circuit, small emergent pumps are linked to the tube connecting the heat exchangers.

Water is used as a heat transfer agent and the two reservoirs are filled accordingly. An electronic data acquisition interface has been developed, and the installation is powered by a 12 V generator. Two *K*-type sensors have been installed in the reservoirs to monitor the temperatures of both the hot and cold sides. For the second experiment, the set-up remains unchanged, but the sondes (temperature sensors) are now placed on the cold side of the exchanger, while the other side remains connected to the reservoir, allowing for the efficient dissipation of heat.

Findings and analysis

Conducting scientific research on thermoelectric devices offers several benefits, including enhancing efficiency, reducing costs, promoting sustainable energy, discovering new applications, and understanding fundamental physics. First and foremost, scientists can improve the efficiency of thermoelectric devices by developing novel materials and techniques that facilitate better energy conversion and utilization. By studying thermoelectric materials and devices, researchers can also identify cost-effective ways to manufacture and enhance their performance. Moreover, thermoelectric devices have the potential to harness waste heat and convert it into valuable energy, which can significantly reduce overall energy consumption and promote sustainability. Additionally, ongoing research into thermoelectric devices may lead to the discovery of new applications in fields such as transportation, renewable energy, and space exploration, which can revolutionize the way we use and produce energy. Finally, the study of thermoelectric materials and devices provides insights into fundamental physics, including thermal and electrical transport, energy conversion, and materials science. Therefore, scientific research on thermoelectric devices is critical for improving their performance, expanding their applications, and promoting sustainability in energy use. Our research on thermoelectric devices involved conducting two experiments to gather extensive information. The knowledge and data we obtained enabled us to effectively categorize the devices using the Peltier model. With our findings, we can better understand the behavior and performance of thermoelectric devices, which can lead to improvements in their design and application.

The 1st experience

In our experimental set-up, we opted to use water as the coolant fluid and created two closed circuits, one for the hot side and another for the cold side of the thermoelectric device. To obtain accurate measurements, we placed temperature sensors inside the containers to monitor the temperature of the water. The data collected from our experiment is presented in fig. 5, providing a visual representation of the temperature changes over time for the hot and cold sides of the device. The presented results offer valuable insights into the behavior of the thermoelectric device under the experimental conditions. By examining the temperature changes over time, we can draw conclusions about the efficiency and effectiveness of the device. Our experimental approach provides a solid foundation for future research into thermoelectric devices, as it offers a reliable and effective means of measuring and analyzing device performance.

The plot in fig. 5 displays the cold temperature readings taken by the Arduino microcontroller at the outset of the experiment, denoted as $t = 0$ seconds, indicating an ambient temperature of 17 °C. As the experiment progressed, the temperature showed an exponential decrease, eventually reaching 7 °C. The drop in temperature was accomplished through the Peltier effect, which lowered the temperature, and also through the heating of the heat transfer fluid due to electrical dissipation. This combination of cooling mechanisms led to a significant temperature reduction over the course of the experiment. Taken as a whole, the outcomes of the study furnish compelling proof that the thermoelectric models employed in the experiment are successful in reducing temperatures, and that utilizing water as the coolant fluid represents a viable approach. These findings have important implications for a wide range of applications, as the thermoelectric cooling method has the potential to be a highly effective and energy-efficient alternative to traditional cooling methods. Furthermore, the use of water as the coolant fluid is not only effective, but also widely available and environmentally friendly, making it a practical and sustainable solution for cooling purposes. Therefore, these findings underscore the value of thermoelectric cooling and highlight the significance of water as a coolant fluid for achieving efficient and sustainable cooling.

Figure 6 displays a graph that depicts the temperature variations throughout the experiment. At the outset, the temperature registered 17 °C, and as the experiment progressed, it gradually increased due to the heat generated by the thermoelectric components and the Joule effect dissipation. The heat was then transferred through conduction to the heat exchanger, which facilitated heat transfer to the coolant. The coolant, which was water, circulated through a closed circuit system utilizing a submersible pump. Meanwhile, fig. 7 illustrates the performance of the thermoelectric assembly, with an impressive yield value of approximately 84%, indicating the successful accomplishment of the experimental objectives. These results have significant implications for future investigations involving alternative configurations and applications of thermoelectric components.

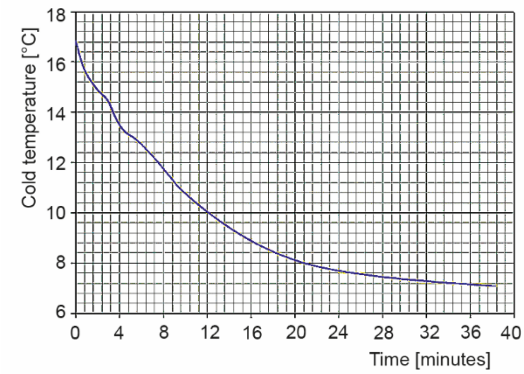

Figure 5. Cold temperature that the first experiment Arduino microcontroller measured at time *t* = 0 seconds

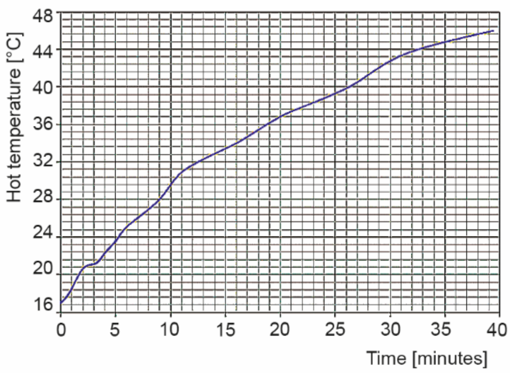

Figure 6. Hot temperature during the first experiment

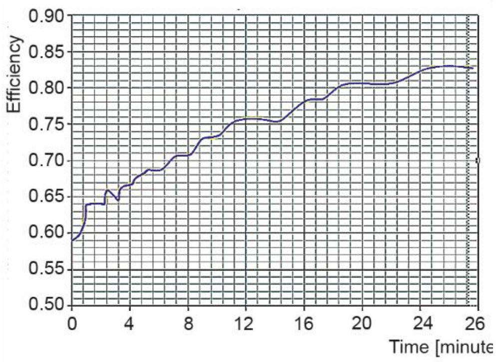

Figure 7. The COP of the first experience

In addition, they offer valuable insights into the potential of thermoelectric technology to provide efficient and sustainable cooling solutions, serving as a benchmark for future research endeavors.

The 2nd experience

In this experiment, we utilized two distinct cooling methods, water and air, to facilitate heat transfer for heat dissipation and the cold-weather coat, respectively. To monitor the temperature of the exchanger's surface, temperature sensors were installed. The results are presented in fig. 8, which depicts the temperature variations throughout the experiment. At the outset of the experiment, the temperature registered 28 °C, and as the experiment progressed, it gradually decreased until it reached 1 °C. It's worth noting that no coolant was used in the cold exchanger, and heat exchange to the air was relied upon instead. These outcomes underscore the effectiveness of using water and air as coolants and offer insights into the potential of these cooling techniques for various applications. Moreover, the results highlight the importance of carefully selecting and implementing appropriate cooling methods for specific applications to ensure optimal performance and energy efficiency.

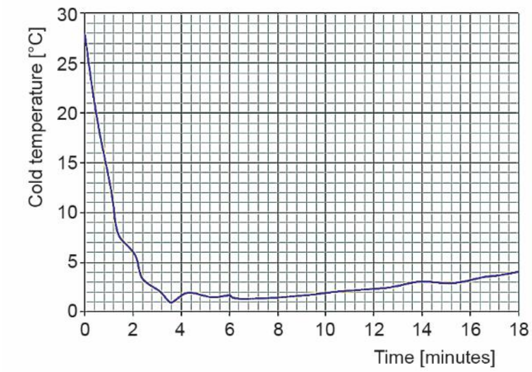

Figure 8. The second experiment Arduino microcontroller measured the cold temperature at time *t* = 0 seconds

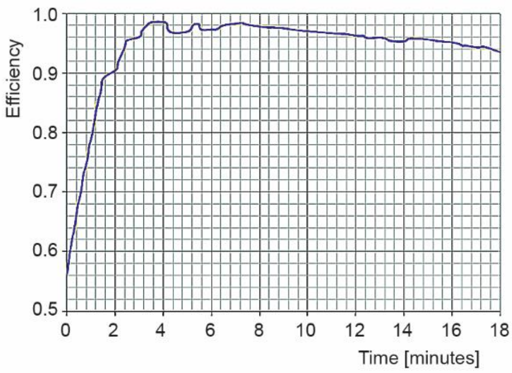

Figure 9. The COP of the second experience

Figure 9 exhibits the remarkable yield achieved for the assembly, which reached an impressive range of approximately 97-95%. These outstanding outcomes showcase the assembly exceptional efficiency and potential for a wide range of applications in both research and industrial settings, particularly for small-scale installations. These results are highly promising and underline the importance of this investigation in propelling the advancement of more efficient and cost-effective systems. The findings provide valuable insights into the optimal design and utilization of thermoelectric systems and have significant implications for the development of sustainable and energy-efficient technologies in the future.

Conclusions

During this project, we conducted an experimental study of cooling using the Peltier effect. Our research was divided into two parts. The first experience is installing a coolant fluid, such as water, which circulates in two closed circuits. The first circuit is connected to the hot side of the Peltier peripheric, where an aluminum heat exchanger is located. The second is also connected to a heat exchanger to obtain cold. In the second experiment, we investigated air cooling, that is, cooling without using coolant. In this study, we investigated the effect of changing the coolant flow rate and thermal resistance of cold-side and hot-side heatsinks on the performance of TEC. Experimental studies are conducted to make multiple thermoelectric devices and aluminum water heat exchangers more effective and efficient at cooling electronic instruments. Based on the results of this study, we can conclude that:

- Finding the adequate coolant rate flow has a direct effect on the COP of the TEC cooling system and
- When the thermal resistance of the cold-side heatsink is increased, it causes a decrease in the temperature of the TEC cold side.

The TEC cooling systems are found to have inverse effects on COP when the hot side and the cool side are compared. The obtained results are in the form of curves. These results allow us to categorize the use of thermoelectric. We quote:

- Mini fridge,
- Small-scale fresh fountains,
- The CPU cooling for computer stations or gamer-type PC, and
- Crates for the transport of medicines.

Finally, this experimental investigation opens possibilities for industry and scientific research.

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