Enhancement of the Hydraulic cooling system by Thermoelectric

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Abstract

Imperfect hydraulic oil quality, including oil temperature that is too high, will cause the hydraulic oil to bubble. It causes the hydraulic system to stop working. Also, in countries near the equator, the ambient temperature is quite high at 35-40 degrees Celsius, which is well known that the operating temperature of hydraulic oil should not exceed 70 degrees Celsius in equipment operation. This research aimed to focus on the temperature reduction experiments of hydraulic oil by using a set of thermoelectric modules for cooling. Thermoelectric modules are environmentally friendly and compact devices that are easy to install. Additionally, they require low electrical power to generate cooling and do not contain refrigerants. This experiment created a simulation set of hydraulic system operations that can adjust the heat value of the temperature of the hydraulic oil. The study suggested that the temperature of the hydraulic oil could be reduced by 3-5 degrees Celsius at the flow rate. This helps in reducing air bubbles in the hydraulic oil and also extends the service life of the hydraulic oil.

Keywords: Hydraulic cooling system, Thermoelectric, Hydraulic oil

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Introduction

Hydraulic systems are widely used in industrial and mechanical applications due to their highpower density and precise control capabilities. However, excessive heat generation within these systems remains one of the most common causes of performance degradation and mechanical failure. In particular, hydraulic oil plays a crucial role in energy transmission, lubrication, and component cooling. When the oil temperature exceeds the recommended operating limit, typically around 70 °C, the viscosity of the fluid decreases significantly, leading to reduced lubrication efficiency and the formation of vapor bubbles within the system. These bubbles, or cavitation effects, can interrupt hydraulic flow and cause severe damage to components such as pumps and valves. In tropical and equatorial regions, where ambient temperatures often range from 35 °C to 40 °C, the challenge of maintaining optimal oil temperature becomes even more critical. Conventional cooling methods, including finned radiators or water-cooled heat exchangers, are often bulky, energy-intensive, and require regular maintenance. As a result, alternative cooling technologies that are compact, efficient, and environmentally friendly are gaining increasing attention. Thermoelectric cooling modules, based on the Peltier effect, present a promising solution to this issue. These devices offer several advantages, including small size, low power consumption, and the absence of refrigerants, making them suitable for sustainable and compact cooling systems. This research investigates the potential of integrating thermoelectric modules into a hydraulic system to reduce oil temperature under controlled laboratory conditions. Efficient thermal management is a critical factor in the design and operation of hydraulic systems. Excessive oil temperature can cause viscosity degradation, oxidation, and reduced component lifespan, which ultimately lead to system inefficiency and failure. According to Karpenko et al. (2014), maintaining hydraulic oil within an optimal temperature range is essential for ensuring energy efficiency and stable pressure transmission. In conventional systems, air-cooled and water-cooled radiators are the most commonly used methods for heat dissipation. However, these systems are often bulky, require frequent maintenance, and may not be suitable for compact or mobile hydraulic units (Zhou et al., 2020). Recent studies have explored the integration of thermoelectric cooling (TEC) modules as an alternative approach to heat removal in small- and medium-scale systems. TEC modules, operating on the Peltier effect, generate a temperature difference across two semiconductor junctions when an electric current flows through them. This solid-state technology allows for compact, silent, and refrigerant-free cooling solutions (Rowe, 2018). Compared with conventional vapor-compression systems, TECs provide rapid response times, minimal maintenance, and easy integration with electronic controls (Jouhara & Chau-han, 2021). In the context of hydraulic systems, several researchers have proposed the use of thermoelectric modules for localized cooling of hydraulic oil or system components. Al-Taie et al. (2019) demon-strated that incorporating TECs into an oil circulation system can reduce working fluid temperatures by 4–6 °C, improving both fluid stability and equipment performance. Similarly, Patil and Jadhav (2022) reported that thermoelectric cooling can effectively suppress cavitation and maintain oil viscosity under high-load conditions. These findings indicate that TEC-based cooling offers a promising route for improving energy efficiency and reliability, particularly in warm climates where ambient temperatures exacerbate system overheating. In addition, the adoption of thermoelectric modules aligns with modern trends in green and sustainable engineering. As TECs do not require refrigerants or moving parts, they minimize environmental impact and operational noise while providing flexible integration into existing hydraulic architectures (El-Desouky et al., 2023). Despite these advantages, challenges remain in optimizing the heat transfer interface between the TEC and the hydraulic reservoir, as well as in managing the electrical energy consumption relative to cooling output. Continued research is therefore essential to improve the thermal efficiency and system design of TEC-based hydraulic cooling systems.

From the study, the researchers have created an experimental set to study the cooling system of the hydraulic system using thermoelectric cooling. This experiment will find the efficiency of the system.

Experimental Setup

This experiment aims to study the cooling efficiency of hydraulic oil using a thermoelectric cooler (TEC) plate, which can be controlled by electric current. The heat exchange between hydraulic oil and the TEC plate will be tested under different flow and power conditions.

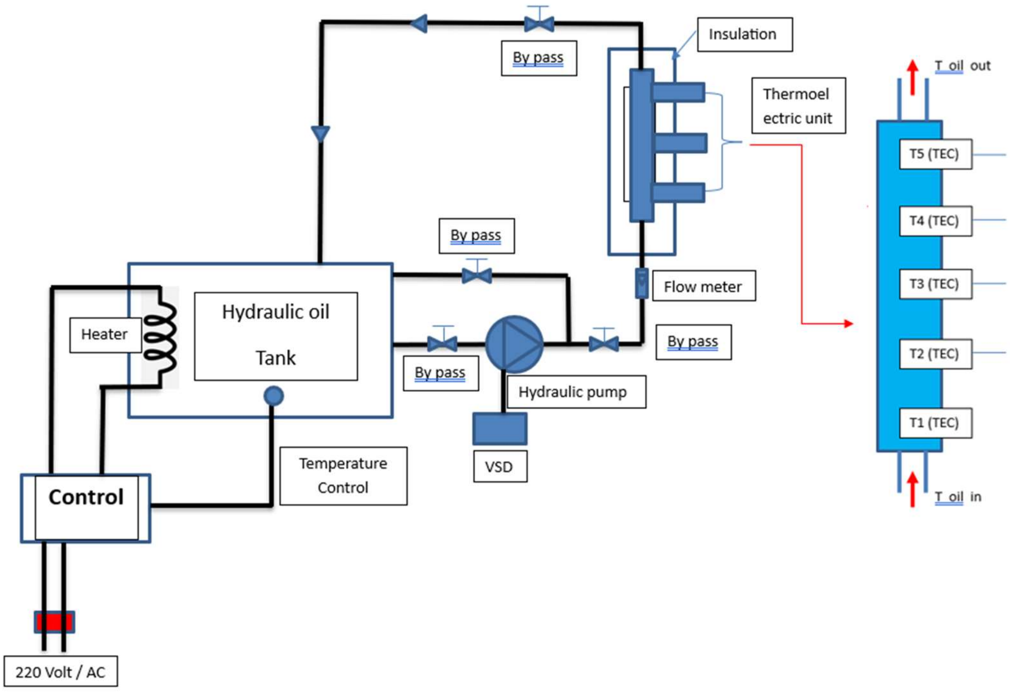

Figure 1 shows the experimental schematic.

Design and construction of cooling units

Part 1. Cooling Unit. Heat Transfer from Oil to TEC: This is the most important point. The hydraulic oil must be in effective contact with the cold side of the TEC. Since the TEC is 40x40 mm, which is relatively small compared to the amount of oil flowing, we want to create a "Cold Block" through which the hydraulic oil will flow and contact the cold side of the TEC. It should be a metal with high thermal conductivity, such as aluminum or copper. It can be a metal block with channels for the oil to flow through (e.g., threaded or multiple small channels). On top of the block, there will be a flat area for the TEC to be placed between the cold block (for oil) and the water box (for waste heat). A high-quality thermal paste must be applied to both sides of the TEC to reduce thermal resistance. It must be ensured that no hydraulic oil leaks into the TEC or water box.

Part 2: Waste Heat Dissipation Section (TEC ↔ Water Box ↔ Fan ↔ Air): The 240 mm water box acts as a medium for absorbing heat from the hot side of the TEC. Installation: Place the hot side of the TEC flush with the surface of the water box using thermal paste. Water Flow in the Water Box: If your water box has inlet and outlet pipes, connect a small water pump to circulate water within the water box to an additional radiator. Alternatively, use a closed system filled with coolant. 40*40 mm fan: Installed on the water box to blow air through the water box, increasing cooling efficiency to the atmosphere.

Part 3 Hydraulic Oil Circulation System:

- Reservoir: For storing hydraulic oil.

- Pump: For circulating oil from the reservoir, through the TEC cooling block, and back into the reservoir.

- Flow meter: For measuring the oil flow rate to your specified rate.1-10 L/min

Part 4. Temperature Measurement System:

Temperature Sensors: At least three points before entering the TEC cold block (oil inlet).

After leaving the TEC cold block (oil outlet). Oil temperature in the reservoir (to view the average system temperature). (Additional) Ambient temperature.

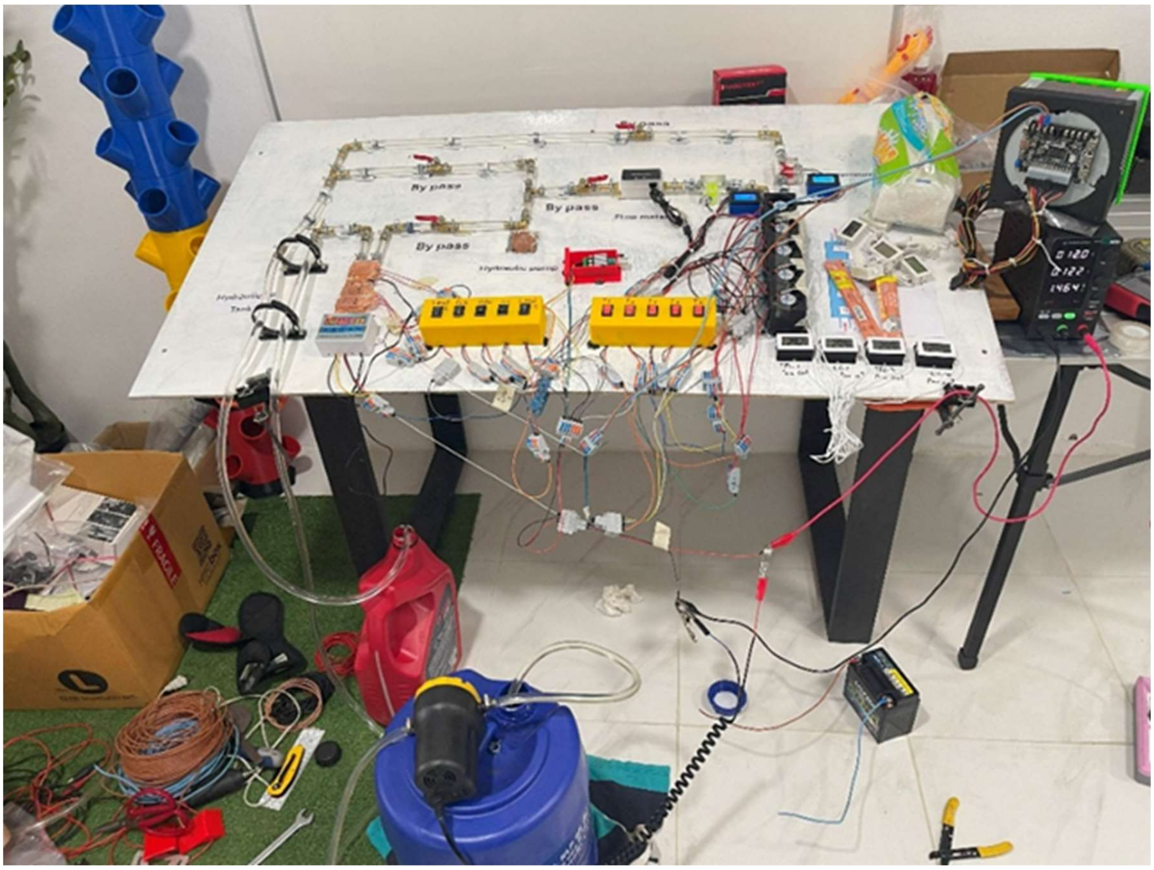

Figure 2 shows the circuit connection for experimental results

Cooling Effect Q_c produced by the TEC can be calculated using the equation. (1)

$$Q_c = \dot{m}_f \, C_p \left(T_{i,f} - T_{o,f}\right) \quad (1)$$

When

Q_c = coolant sucked out by TEC (W)

$\dot{m}_f$ = Oil mass flow rate (kg/s)

C_p = Specific heat of oil (J/kg·K)

$T_{i,f}$ = Inlet oil temperature (°C)

$T_{o,f}$ = Oil outlet temperature (°C)

Where C_p is the specific heat of the hydraulic oil, and the mass flow rate $\dot{m}_f$ of the hydraulic oil. It can be calculated using an equation. (2)

$$\dot{m}_f = \rho \, \dot{V} \quad (2)$$

When

$\dot{m}_f$ = Oil mass flow rate (kg/s)

ρ = Oil density (kg/m³)

$\dot{V}$ = Volumetric flow rate (m³/s)

The thermal resistance of the heat exchanger for hydraulic oil and TEC is calculated using the equation. (3)

$$R_c = \frac{T_{i,f} - T_a}{Q_c} \quad (3)$$

When

R_c = Thermal resistance (K/W)

$T_{i,f}$ = Inlet oil temperature (°C)

T_a = Average block temperature (°C)

Q_c = coolant sucked out by TEC (W)

Where T_a Is the average temperature of the heat sink or hydraulic block, which can be determined from the equation. (4)

$$T_a = \frac{T_{i,f} + T_{o,f}}{2} \quad (4)$$

When

T_a = Average block temperature (°C)

$T_{i,f}$ = Inlet oil temperature (°C)

$T_{o,f}$ = Oil outlet temperature (°C)

The coefficient of performance (COP) of the TEC can be calculated with the following equation. (5)

$$COP = \frac{Q_c}{P} \quad (5)$$

When

COP = coefficient of performance of the TEC

Q_c = coolant sucked out by TEC (W)

P = Electrical power supplied to TEC (W)

Discussion

This experiment aims to study the cooling efficiency of hydraulic oil No. 68 operating at room temperature, 34–36 °C, using a thermos-electric cooler (TEC) sheet under different initial temperatures, namely 40, 50, 60, 70, and 80 °C, by controlling the flow rate between 1–10 liters /minute (L/min). And to determine the efficiency of TEC.

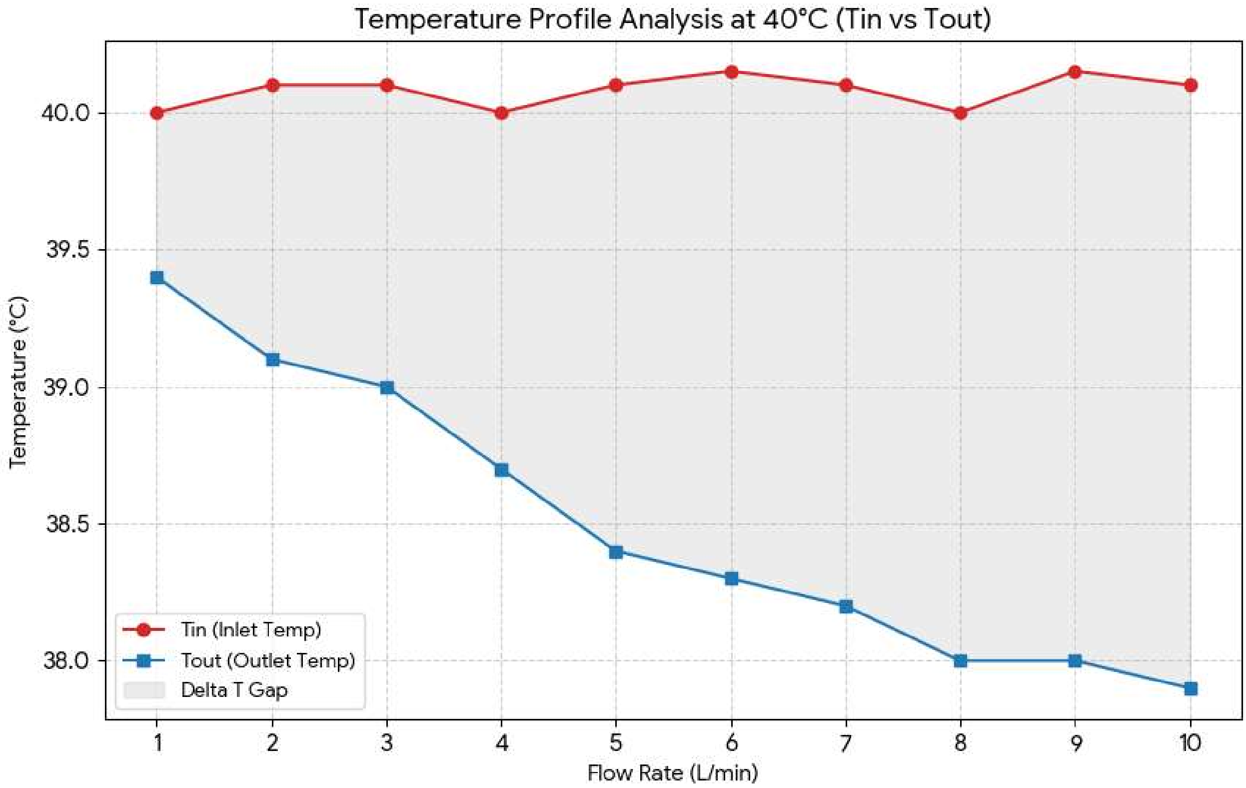

Figure 3 shows the flow rate of 1-10 L/min at a temperature of 40 °C.

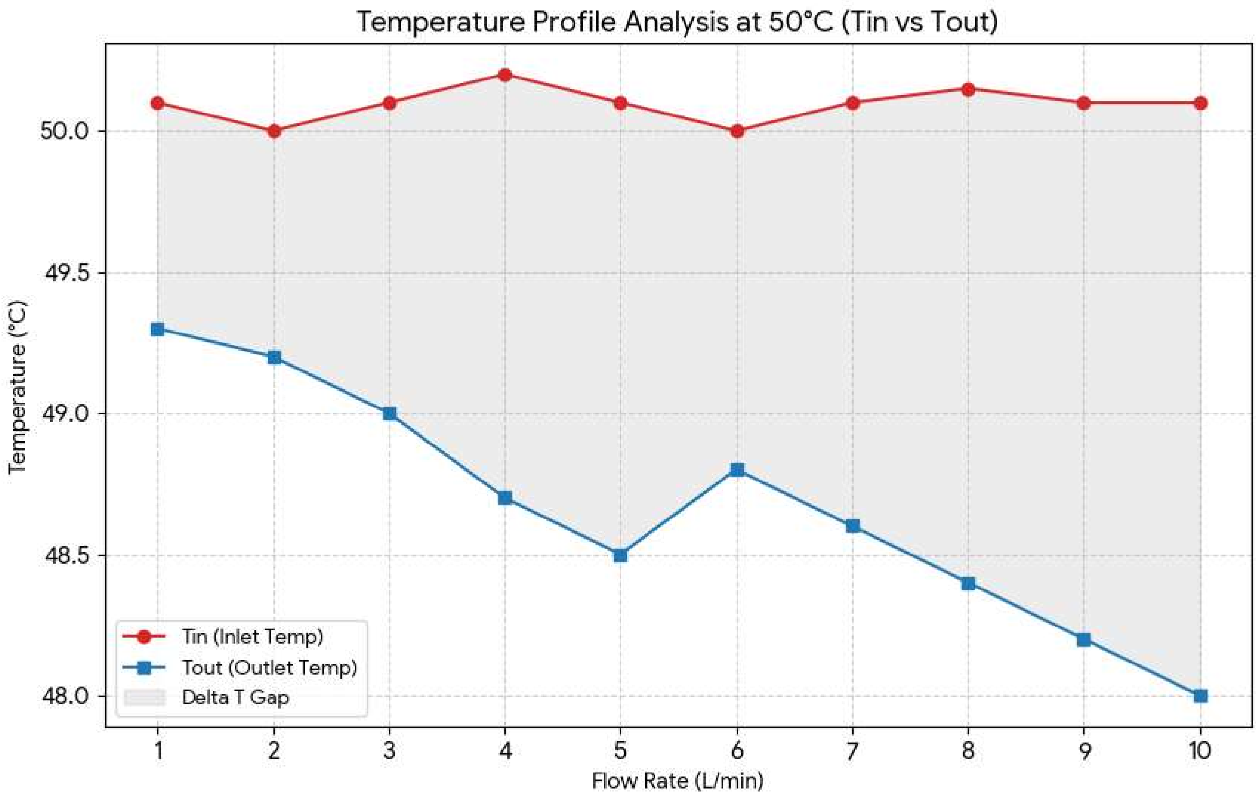

Figure 4 shows the flow rate of 1-10 L/min at a temperature of 50 °C.

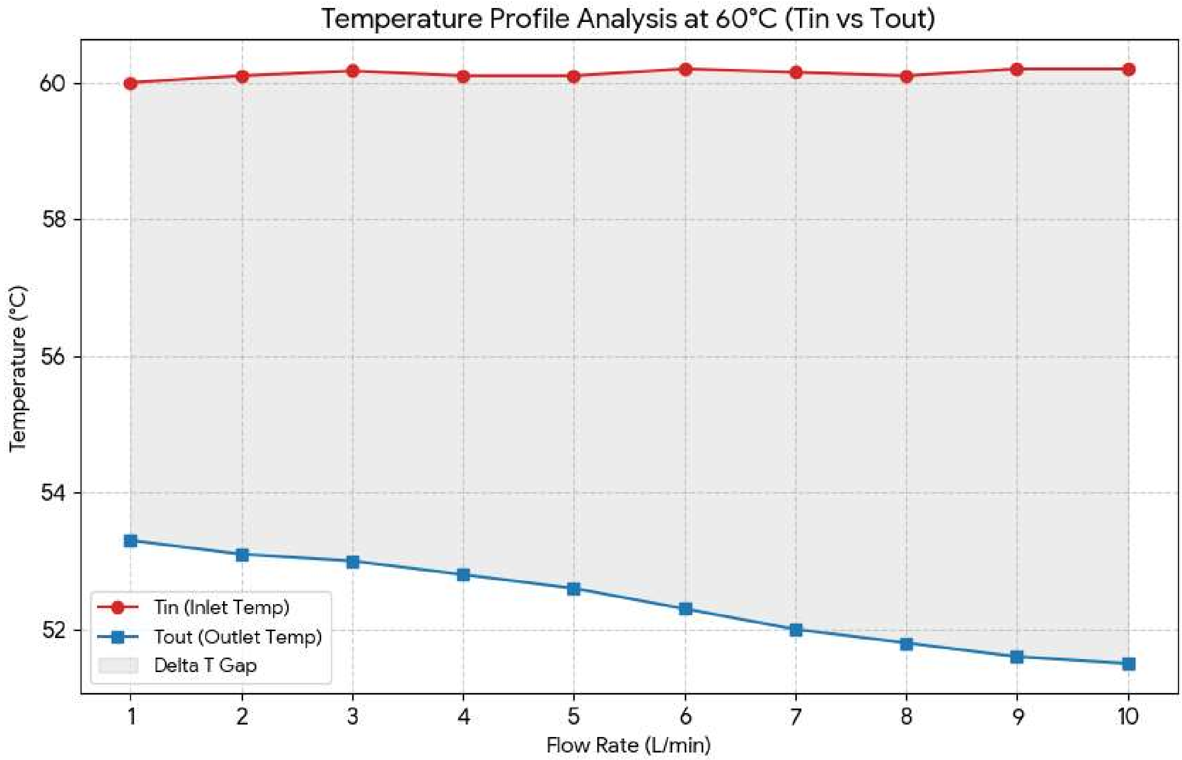

Figure 5 shows the flow rate of 1-10 L/min at a temperature of 60 °C.

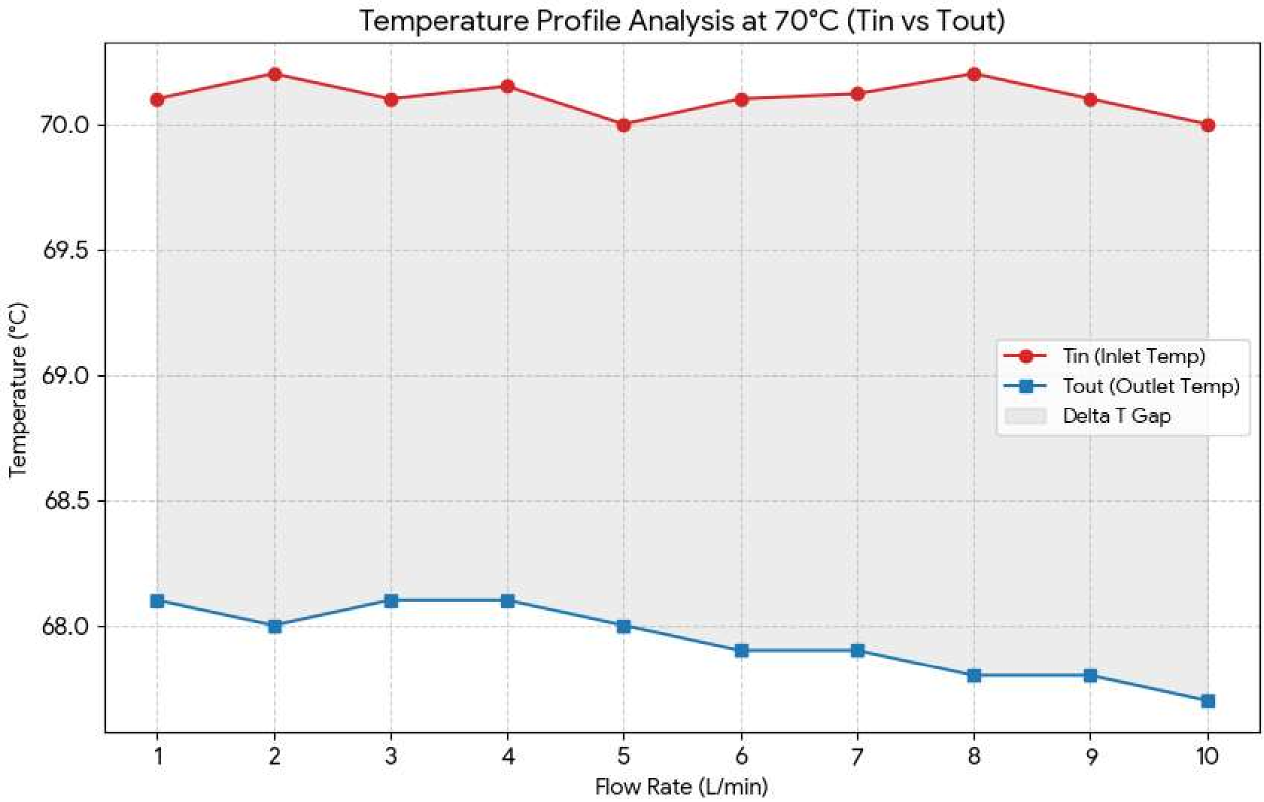

Figure 6 shows the flow rate of 1-10 L/min at a temperature of 70 °C

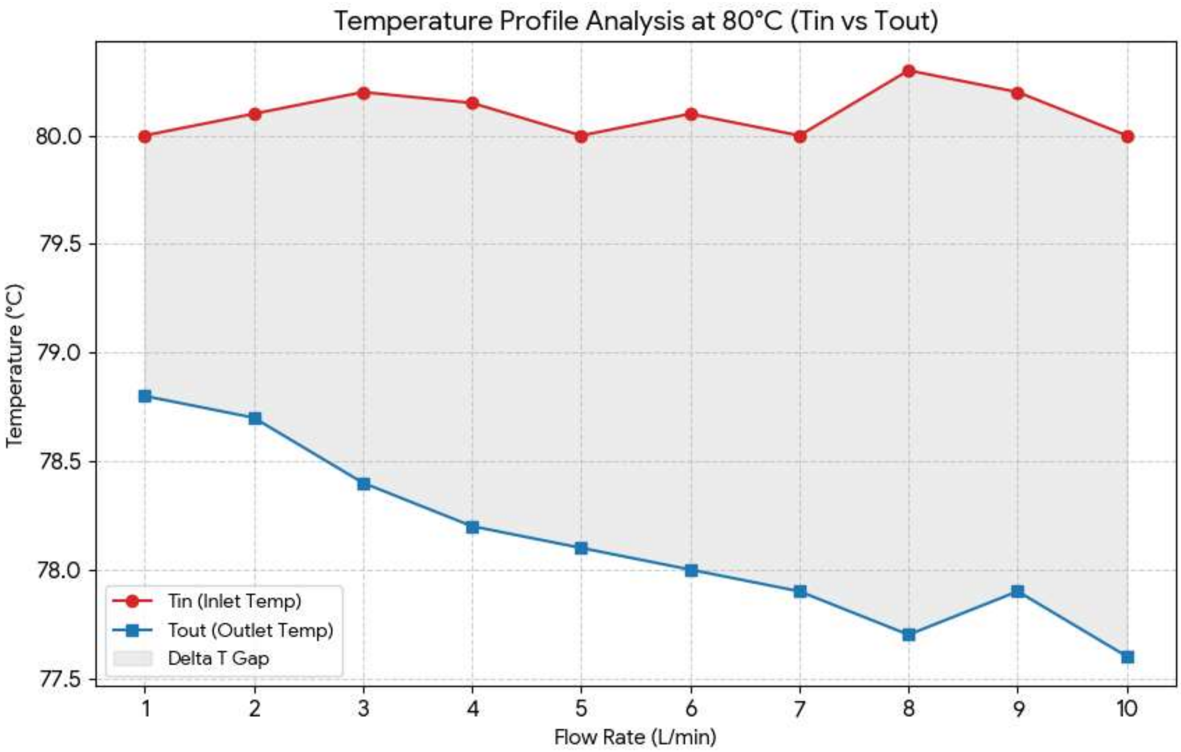

Figure 7 shows the flow rate of 1-10 L/min at a temperature of 80 ℃

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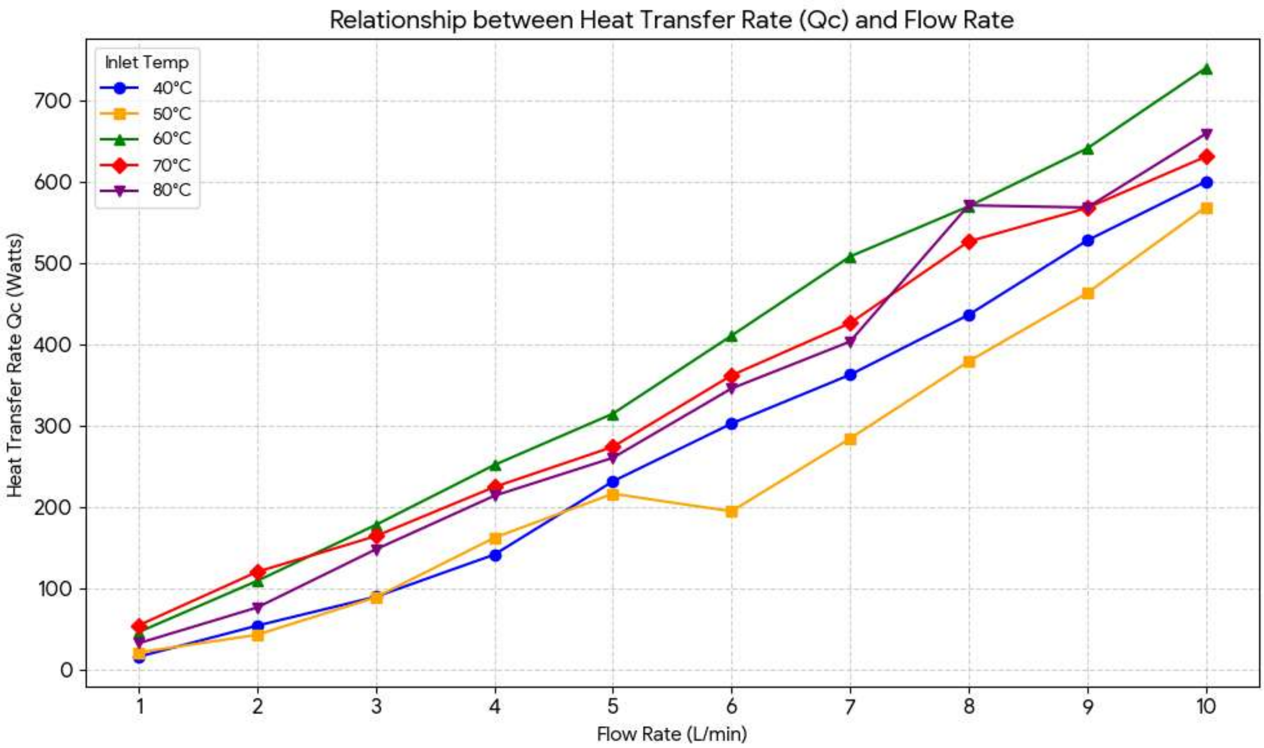

Figure 8: shows the efficiency of the cooling system.

Experiments to determine the heat input of hydraulic oil at temperatures from 40°C to 80°C, with flow rates ranging from 1 liter per minute to 10 liters per minute, found that at 40°C, a flow rate of 10 liters per minute can reduce heat by 2.2°C, at 50°C, a flow rate of 10 liters per minute can reduce heat by 2.7°C, at 60°C, a flow rate of 10 liters per minute can reduce heat by 2.9°C, at 70°C, a flow rate of 8 liters per minute can reduce heat by 2.4°C, and at 80°C, a flow rate of 10 liters per minute can reduce heat by 3°C

From picture 8. In the experiment, it was found that the efficiency of the hydraulic oil cooling device at the best temperature was at 60 °C, a flow rate of 10 liters/min, and the heat transfer value read as 739.58 watts.

Conclusion

A study of the cooling efficiency of hydraulic oil No. 68 using a thermoelectric cooler (TEC) at inlet oil temperatures and flow rates of 1-10 L/min can summarize the results as follows:

1. Effect of Flow Rate Oil flow rate has a direct effect on system performance. The heat transfer quantity Qc and the coefficient of performance COP tend to vary directly with flow rate across the experimental temperature range. Increasing the flow rate from 10 to 10 L/min promotes turbulent flow, which increases the surface convection coefficient, enabling the system to better extract heat from the oil.

2. Effect of Inlet Temperature oil inlet temperature significantly affects system performance, with behavior divided into three ranges:

• Low temperature range of 40-50°C: Cooling efficiency is not very high due to the oil's high viscosity. This hinders heat transfer.

• The optimum temperature range of 60°C is the optimum operating point, where the system achieves the best temperature difference, resulting in the highest Qc values in the experiment. This is because the oil viscosity reduction is balanced with the TEC plate's capability.

• The high temperature range (70-80°C): System efficiency begins to decrease or stabilize compared to the 60°C range due to the limitations of the thermoelectric plate's thermal saturation.

3. Maximum Performance Data Analysis of the experimental results revealed that the optimal conditions for this cooling system are:

• Inlet oil temperature: 60°C

• Flow rate: 10-L/min

• Maximum heat transfer rate (Qc, max): $739.58-Watts.

Acknowledgments

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References

Ananacha, T., Rattanabanlue, A., and Watcharodom, N. (2024). The Enhancement of Split-Type Air Conditioner by Improving the Cooling System for Residence. International Journal of Science and Innovative Technology, Vol.7, No.1, 2024, pp.89–99.

Al-Taie, A. M., Al-Zubaidi, M. S., & Jasim, A. A. (2019). Experimental study of thermoelectric module for oil cooling application. International Journal of Mechanical Engineering and Technology, 10(4), 555–563.

El-Desouky, A. A., Khalil, A. S., & Soliman, H. A. (2023). Performance analysis of Peltier-based thermoelectric cooling for sustainable thermal management systems. Energy Reports, 9(1), 1260–1272. https://doi.org/10.1016/j.egyr.2023.02.015

Jouhara, H., & Chauhan, A. (2021). Advances in thermoelectric cooling technologies: A review. Applied Thermal Engineering, 196, 117241. https://doi.org/10.1016/j.applthermaleng.2021.117241

Karpenko, O., Makarenko, V., & Hrinov, V. (2014). Influence of hydraulic oil temperature on system performance and energy losses. Journal of Mechanical Engineering Research, 6(2), 45–52.

Patil, R. S., & Jadhav, P. S. (2022). Application of Peltier module for hydraulic oil temperature control. Journal of Thermal Science and Engineering Applications, 14(9), 091001. https://doi.org/10.1115/1.4054962

Rowe, D. M. (2018). Thermoelectrics handbook: Macro to nano. CRC Press.

Watcharodom, N. (2016). Design and Construction of Energy-Saving Air-Conditioning Innovation for Small-Scale Residences, in Proc. 12th Conf. on E-NETT, 2016, pp.1321–1328.

________. (2018). Design and Construction of Split-Type Air-Conditioning System Using Thermosyphon Heat Pipe, in Proc. 14th Conf. on E-NETT, 2018, pp.45–50.

Zhou, Y., Zhao, L., & Wang, H. (2020). Optimization of hydraulic oil cooling using compact heat exchangers. Journal of Thermal Science, 29(5), 1320–1332.