

DEVELOPMENT OF COOLING AND EXHAUST EMISSION REDUCTION SYSTEM WITH THERMOELECTRIC-BASED

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ABSTRACT

Vehicle exhaust emissions are a major source of air pollution. This research aims to reduce emissions by developing a thermoelectric system using Peltier modules integrated with a single-room type heat exchanger. The cold side of the Peltier serves as a fuel cooler. The method used is an experiment with variations of large and small radiators. The results show that the small radiator increases the fuel temperature to 39.5°C compared to 34.4°C in the large radiator. This condition reduced CO emissions from 4.99% to 4.22%, and HC from 429.3 ppm to 294.7 ppm. The cold side temperature of TEC 1 on the large radiator reached -8.6°C, while that of the small radiator was only -1.1°C. Although cooling performance decreased, the increase in fuel temperature favored combustion efficiency and emission reduction.

Keywords: exhaust emissions; fuel temperature; radiator; thermoelectric

INTRODUCTION

Today, Vehicles in Indonesia every year experience an increase in quantity (Nisak & Prakoso, 2012). Badan Pusat Statistik (2023) published data on the number of passenger car vehicle ownership in Indonesia as many as 18.2 million. Therefore, exhaust emissions are one of the main causes of increasing air pollution (Ismiyati et al., 2014). The use of fossil fuel vehicles is directly proportional to the increase in exhaust emissions. The fuel combustion process in vehicles produces key pollutants such as CO_x, NO_x, SO_x, and HC (Yusrianti, 2018). The transportation sector as a whole contributes greatly to air pollution, including 100% of lead emissions, 89% of hydrocarbons, 64% of nitrogen oxides, and almost all carbon monoxide emissions (The World Bank, in G. Gunawan, 2015). At certain levels, this air pollution can cause health problems in the respiratory system, such as lower respiratory tract infections, chronic obstructive pulmonary disease (COPD), tuberculosis, and lung cancer (Rosyidah, 2016). In addition, the results of exhaust gas emissions will damage the environment such as global warming which can disrupt living ecosystems (Purnomoasri & Handayani, 2022).

Thermo Electric Cooling (TEC) or Peltier modules as a cooling system is considered environmentally friendly and reliable (Tang et al., 2023). The TEC system makes use of the seebeck effect and the peltier effect where the seebeck effect takes advantage of the temperature difference to generate electricity in the TEC circuit, while the peltier effect creates a temperature difference when the electric current is passed through the TEC circuit, so the TEC module will depend on the energy conversion from the seebeck effect to the peltier effect (Prasetyo et al., 2022). Heat control on the TEC can be achieved by increasing the heat transfer on the heat side of the TEC system and increasing the number of TEC coolers (Cai, et al., 2019). The cooling performance of TEC is influenced by the smooth circulation of fluid on the hot side; if the hot side is cooled with fluid flow, such as water, the temperature on the cold side of the TEC will increase significantly. The utilization of TEC in the automotive field, especially in improving the safety and comfort aspects of driving, has been widely developed. Lyu et al. (2021) designed a battery cooling system that combines TEC modules with fluid circulation. Setiawan, et al. (2018) researched an air conditioning cooling system using TEC modules, in which they added heatsinks and fans to optimize the cooling process. Meanwhile, Hsueh (2012) developed a TEC-based cooling system applied to vehicle drum brakes.

The heat exchanger is an important component in the process of changing fluid temperature (Prasetyo, in Rizqi et al., 2022). The TEC module absorbs heat through a single room-type heat exchanger component, through which the fluid only passes once during the heat transfer process. The effectiveness of heat transfer in the heat exchanger is determined by the temperature of the incoming fluid (Rizqi et al., 2022). TEC can be combined with fluid circulation as heat absorption on the heat side of the peltier. A constant low flow circulation will have an effect on TEC cooling, when the hot side is cooled with flowing fluids such as water, this can significantly increase the cold side (Dizaji, in Wahyu, 2024).

In the application of TEC-based cooling systems in gasoline or diesel-fueled motor vehicles, the internal combustion engine (ICE) fuel system has a fluid flow that has the potential to absorb heat (Sadighi Dizaji, et al., 2016). However, so far, there has been no research that utilizes the ICE fuel system as a heat-absorbing medium from the heat side of the Peltier module. The impact of this heat absorption is the increase in fuel temperature. Several previous studies have shown that fuel heating in ICEs can reduce exhaust emissions. Kusmanto and Winoko, (2019) stated that fuel heating increases engine efficiency due to decreased viscosity and increased fuel heat, which leads to better mixing of air and fuel. Optimal mixing improves engine performance and lowers emissions (Sarsetiyanto et al., 2011). In addition, the fuel temperature increases, making the carbon chain in the fuel more so that the fuel is easier to mix into the air related to the homogeneity of the fuel (Fatma et al., 2017). Therefore, in addition to improving driving comfort and safety, this TEC-based cooling system is also expected to contribute to environmental sustainability.

Radiator dan heat exchanger berperan sebagai media untuk menyerap dan mendinginkan panas dari fluida yang bersirkulasi. (Wijayanta, 2024). Radiators and heat exchangers act as a medium to absorb and cool the heat of the circulating fluid. Radiators with larger cross-sectional areas can improve cooling performance (Andri, et al., 2021). According to Cengel and Ghajar, in Andri, et al., (2021) the problems that occur in radiators when absorbing heat are the discharge rate and radiator dimensions. Therefore, this study not only evaluates the cooling performance of thermoelectric systems with radiator variations, but also analyzes the effect of increasing fuel temperature due to heat absorption as part of efforts to reduce vehicle exhaust emissions.

METHOD

The research method used is the experimental method. The scheme of the experiment carried out is seen in Figure 1 below.

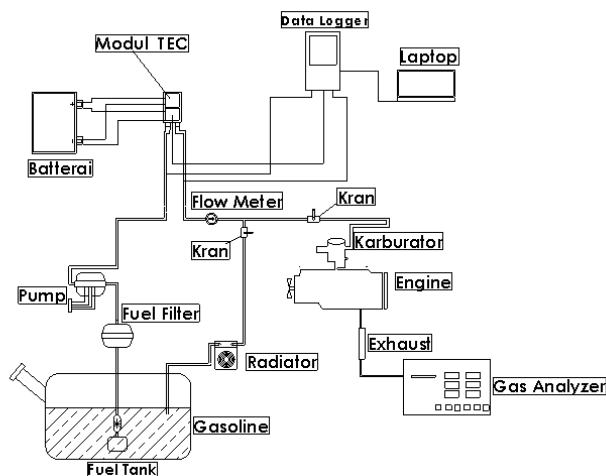


Figure 1 Schematic of the Experiment

This study uses an engine stand with a Toyota 5K engine with a 4-cylinder in-line configuration and a capacity of 1486 cc. A thermoelectric module (TEC/Peltier) is operated using a DC voltage source of 12 volts, which produces a temperature difference (ΔT) between the hot and cold sides of the module. One side absorbs heat (cooling side), while the other side releases heat (heat side). The ΔT ($T(\text{Hot}) - T(\text{Cold})$) value of the module tends to be stable, where a decrease in temperature on the hot side will increase the cooling performance on the cold side. To reduce the temperature of the hot side, the Peltier module is attached to a heat exchanger integrated with the fuel line, precisely between the fuel filter and fuel injector. Fuel pumped from the pump with a flow rate of 3 L/m is flowed into the heat exchanger to absorb heat, then forwarded to the flow meter. The heat exchanger used is a groove heat exchanger. After passing through the flow meter, the fuel flow is divided into two: the first path to the fuel injector to be injected into the combustion chamber, and the second path to the radiator to be cooled before flowing back into the tank, so that when circulating, the flow has a normal temperature. Two types of radiators are used: a large radiator with a diameter of 12 x 24 cm and a small radiator with a diameter of 10 x 12 cm. Exhaust gas emissions from combustion (CO and HC) released through the muffler were then analyzed using a gas analyzer. Each variation experiment was carried out 3 times data collection to get optimal results, and each experiment was carried out for 10 minutes.

Data Logger Installation

Thermocouple probes connected to a data logger were installed at the fluid inlet and outlet of the thermoelectric module (Peltier) to measure the fluid temperature before and after passing through the heat exchanger. In addition, a thermocouple is also placed on the cold side of the Peltier module to monitor the resulting temperature. Considering that the thermocouple has a high sensitivity to the ambient temperature, the installation is carried out with additional protection in the form of a layer of aluminum foil or thermal insulation to minimize external temperature interference and ensure the accuracy of measurement data.

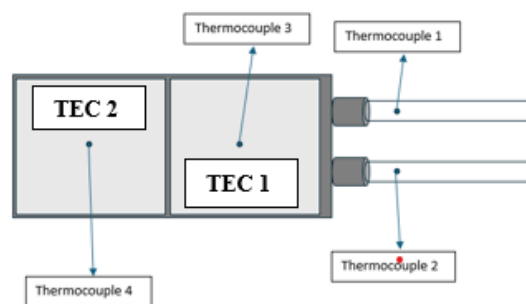


Figure 2 Thermocouple installation

Data Collection Procedure

Data collection was carried out three times, with each repetition lasting 10 minutes. Tests were conducted in an idling vehicle, using a combination of heat exchanger model variations and radiator dimensions. The configuration combinations are as follows:

- Heat exchanger without grooves, with a radiator measuring 10 × 12 cm
- Heat exchanger without grooves with a 24 × 12 cm radiator.
- Heat exchanger with grooves and a 10 × 12 cm radiator.
- Heat exchanger with grooves and a 24 × 12 cm radiator.

Temperature changes on the surface of the TEC were recorded directly onto a laptop via a thermocouple data logger. This tool was also used to monitor and record changes in fuel temperature when entering and exiting the heat exchanger. The time series data obtained was then processed in Microsoft Excel to produce a comparison graph, to provide an overview of

the effect that variations in heat exchanger design and radiator size have on temperature changes.

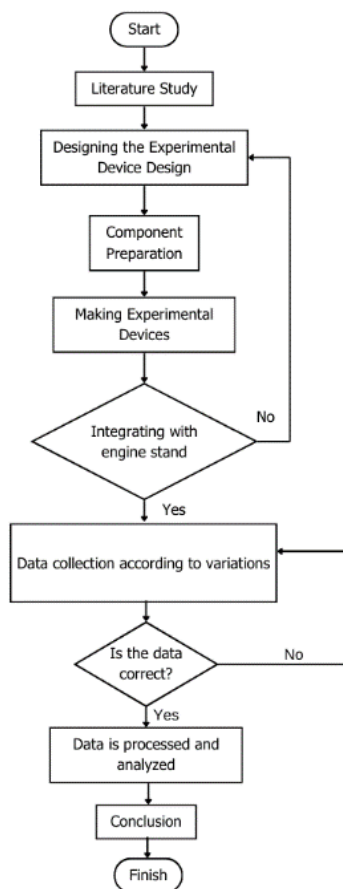


Figure 3 Flowchart of data retrieval

In addition, exhaust emissions were measured using a gas analyser. These results were documented through video recordings and entered into Microsoft Excel tables, which were then processed into graphs to analyse the differences in exhaust emissions in each tested configuration.

RESULT AND DISCUSSION

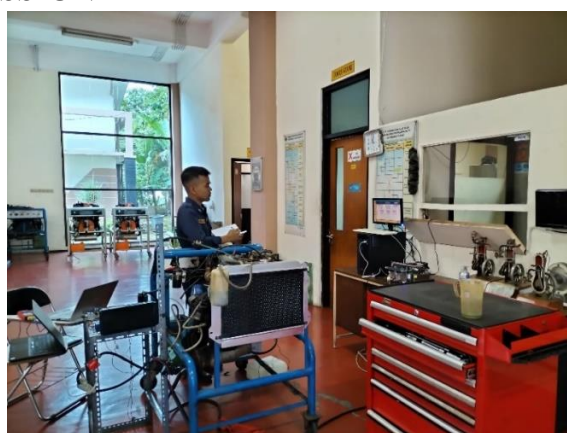


Figure 4. Data Retrieval

This research is motivated by the high level of exhaust emissions produced by motorized vehicles, which contribute significantly to global warming and damage to the ozone layer. This experiment aims to reduce these emissions by creating a device that can improve fuel combustion efficiency by heating the fuel before it enters the combustion chamber. Several

components have been designed and assembled in such a way as to form a system capable of raising the fuel temperature, as shown in the following figure. In addition, the development of this device is also focused on improving the thermoelectric-based cooling system to maintain the stability of the device temperature and prevent performance degradation due to overheating, so that the entire system can work more optimally and efficiently. The following is the research data with a comparison of the use of large radiators and small radiators.

Table 1.
 Experimental results with radiator variation

Radiator Variations	IN Temperature	OUT Temperature	TEC 1	TEC 2	CO Exhaust Gas Emission (%)	HC Exhaust Gas Emissions (ppm)
Large Radiator (24 x 12 cm)	32.17	34.4	-8.6	-4.6	4.99	429.3
Small Radiator (10 x 12 cm)	36.0	39.5	-1.1	0.4	4.22	294.7

The table presents a comparison between two types of radiators, large and small, which affect the effectiveness of the cooling system and impact the temperature and exhaust emissions of the vehicle. In general, large radiators have superior cooling performance as they can keep temperatures low. Conversely, the use of small radiators leads to increased temperatures, which can heat the fuel and potentially lower exhaust emissions.

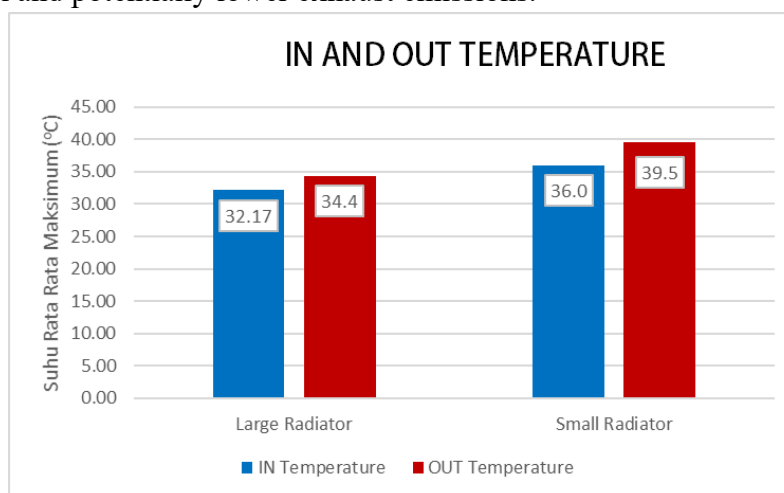


Figure 5. Fuel Flow Inlet and Outlet Temperatures

Figure 5 shows the maximum average temperature of fuel flow in and out of large and small radiators. Broadly speaking, the large radiator has a lower temperature. The large radiator produces an in temperature of 32.17°C and an outlet temperature of 34.4 °C. The use of large radiators can keep the in temperature low which indicates that large radiators have a wider cross-sectional area of the radiator so that the heat dissipation of the flow entering the radiator is more efficient in maintaining the stability of the fuel flow temperature and affecting the results on the temperature on the cold side of the thermoelectric. Large radiators have a large cross-sectional area so that they have wider cooling fins that accelerate the release of fuel flow heat when entering the radiator (Andri et al., 2021). While in small radiators, it shows that the in and out flow temperatures produce higher temperatures. The temperature generated in the inflow is 36 °C, and the outflow is 39.5 °C. The initial temperature when the thermoelectric system is activated is the same temperature, but over time for 10 minutes, the flow with a small radiator increases. The use of small radiators shows that they have low cooling performance due to the small cross-sectional area of the radiator, so that the heat dissipation is not maximized

(Andri et al., 2021). But the higher the flow temperature will have the significant the effect on reducing exhaust emissions in vehicles.

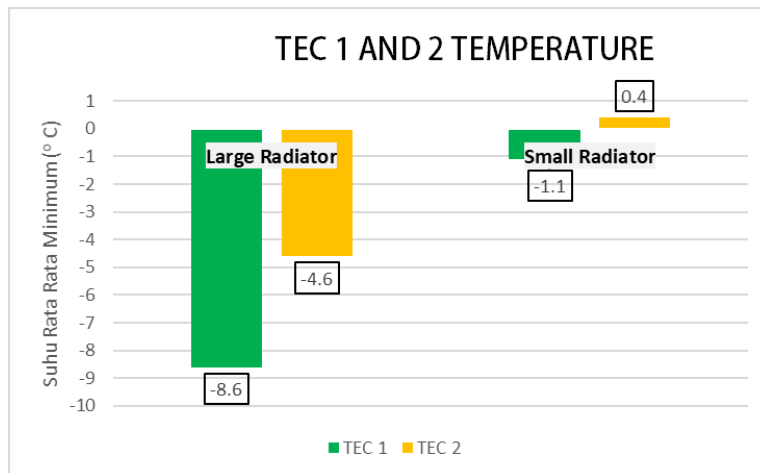


Figure 6 Thermoelectric Temperature

The bar chart in Figure 6 illustrates the average minimum temperatures observed at TEC 1 (the thermoelectric module positioned near the inlet and outlet of the heat exchanger) and TEC 2 (the module located adjacent to TEC 1 but farther from the inlet and outlet). The placement of TEC 2 in proximity to TEC 1 results in elevated fuel temperatures as the fluid passes beneath TEC 1. Kennedy et al. (2021) research shows that the positioning of thermoelectric modules on the surface of a heat exchanger significantly influences heat transfer rates and overall thermoelectric performance. As the fuel continues to flow beneath TEC 2, additional heat absorption occurs from surrounding system components, leading to a further increase in fuel temperature. This difference in location contributes to the variation in cold-side temperatures between TEC 1 and TEC 2. When employing a large radiator, the cold-side temperatures achieved were -8.6°C for TEC 1 and -4.6°C for TEC 2. These findings indicate that the large radiator is effective in maintaining lower temperatures on the cold side of the thermoelectric modules, thereby enhancing heat transfer efficiency across the TEC surfaces. The observed cooling performance corresponds with lower inlet and outlet fuel temperatures, suggesting that the use of a large radiator supports optimal thermoelectric module performance.

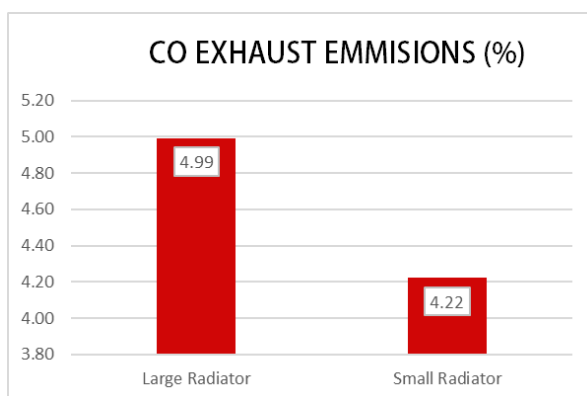


Figure 7. CO Exhaust Gas Emissions

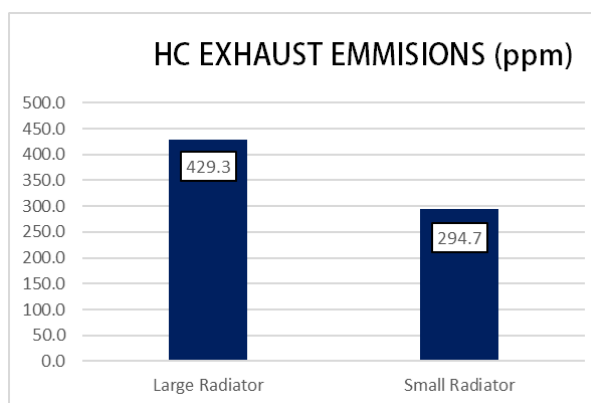


Figure 8. HC Exhaust Gas Emissions

Conversely, under the small radiator configuration, TEC 1 reached a minimum cold-side temperature of 1.1°C , while TEC 2 exhibited a temperature of 0.4°C . These elevated temperatures align with the higher inlet and outlet temperatures observed in the small radiator system, indicating a decline in cooling effectiveness. This reduction in thermal management performance is attributed to the radiator's limited capacity to dissipate heat efficiently.

Nevertheless, the higher fuel temperatures may contribute positively to combustion processes, potentially improving combustion efficiency and supporting reductions in exhaust emissions, as evidenced by decreased levels of carbon monoxide (CO) and hydrocarbons (HC) during operation with the small radiator system.

The bar chart above in figures 7 and 8 presents the exhaust gas emission results from two radiator variations. The data indicate that the use of a large radiator results in relatively higher emissions, with CO levels reaching 4.99% and HC concentrations at 429.3 ppm. In contrast, the small radiator configuration yields lower emissions, with CO at 4.22% and HC at 294.7 ppm. This difference is closely related to the previously discussed fuel outlet temperatures. The small radiator produced a higher fuel outlet temperature of 39.5°C, compared to only 34.4°C with the large radiator. The elevated fuel temperature resulting from the small radiator significantly influences the combustion process. According to Kusmanto and Winoko (2019), preheating the fuel can enhance engine efficiency. This improvement is attributed to the reduction in fuel viscosity and the increase in calorific value, which promotes better fuel–air mixing. Enhanced mixing contributes to improved engine performance and a reduction in exhaust gas emissions by minimizing incomplete combustion.

CONCLUSION

This study shows that the developed thermoelectric system is able to increase the fuel temperature by utilizing the waste heat from the hot side of the Peltier module. This increase in fuel temperature is proven to be effective in reducing vehicle exhaust emissions. The experimental results show that the use of a small radiator produces a higher fuel outlet temperature of 39.5°C, compared to 34.4°C with a large radiator. This increase in temperature directly affects combustion efficiency. Carbon monoxide (CO) emissions were recorded at 4.99% with a large radiator and decreased to 4.22% with a small radiator. Similarly, hydrocarbon (HC) emissions decreased from 429.3 ppm to 294.7 ppm when switching from a large radiator to a small radiator. Although the large radiator is more effective in maintaining lower system temperatures, reaching -8.6°C at TEC 1 and -4.6°C at TEC 2, the small radiator produces higher cold-side temperatures of -1.1°C at TEC 1 and 0.4°C at TEC 2. The small radiator configuration produces more optimal fuel temperatures to improve combustion efficiency, but the large radiator produces lower TEC cold-side temperatures. Therefore, the selection of radiator size in a thermoelectric cooling system must be adjusted to the main purpose of the system application.

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