Thermoelectric Conversion of Motorcycle Exhaust Heat into Alternative Electrical Energy: A Mini Review

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***Abstract*—Heat energy can be harnessed as an alternative source for electricity generation, including waste heat from motorcycle exhaust. Thermoelectric technology enables the direct conversion of this waste heat into electrical energy. This mini-review examines the utilization of motorcycle exhaust heat through thermoelectric systems. The findings indicate that exhaust temperatures can activate thermoelectric modules to produce electrical power, which can be used for applications such as motorcycle-mounted cell phone chargers. The generated electricity can also be stored in batteries to power lighting systems. Given Indonesia's high number of motorcycles, this technology shows strong potential for small-scale renewable energy generation, supporting advancements in sustainable energy solutions.**

Keywords*—*Thermal energy, thermoelectricity, alternative energy, motorcycle exhaust heat

I. INTRODUCTION

Petroleum Energy is the capacity to perform work and is essential for human life, as all activities require it. According to the Big Indonesian Dictionary (KBBI), energy refers to the ability to do work or the power used to conduct various processes. In modern society, electrical energy has become a fundamental necessity [1, 2]. However, excessive reliance on fossil fuels, such as oil, natural gas, and coal, has led to environmental pollution. Furthermore, these non-renewable resources will be depleted in 100 - 200 years if current consumption continues [3]. This situation underscores the urgent need for innovations that utilize sustainable and environmentally friendly alternative energy sources.

One significant form of renewable energy is thermal energy, which can be obtained from various natural and artificial processes, including solar radiation, geothermal activity, combustion, and object friction [4]. Thermal energy is highly versatile, as it can be converted into electricity or used directly for heating. Solar heat, for example, can be harnessed through Solar Photovoltaic Energy Systems (PLTS) that convert sunlight into electrical power via photovoltaic cells. Meanwhile, geothermal heat, produced by the Earth's internal processes, can be exploited in Geothermal Power Plants (PLTP) to generate continuous, base-load electricity.

In addition to these sources, thermal energy can also be recovered from waste heat generated by combustion processes, such as in motor vehicle exhaust systems. In motorcycles, a considerable amount of heat is released through the exhaust during engine operation, yet much of it is wasted without being utilized [5]. This wasted heat represents a valuable yet untapped energy resource [6]. In Indonesia, where most households own at least one motorcycle, the cumulative amount of exhaust heat is substantial [7]. This condition presents a promising opportunity to apply thermoelectric technology, which can directly convert temperature differences into electrical energy via the Seebeck effect.

When implemented in motorcycle exhaust systems, thermoelectric devices can harvest waste heat and generate electricity for small-scale applications, such as charging portable devices (e.g., mobile phones, power banks) or powering vehicle components (e.g., relays, sensors, starters)[2, 8]. The generated electricity can also be stored in batteries for later use, thereby contributing to small-scale renewable energy generation and supporting sustainable energy development. Therefore, the utilization of motorcycle exhaust heat through thermoelectric technology offers a promising approach to recovering wasted energy, reducing fossil fuel dependency, and supporting renewable energy initiatives. This article presents a mini-review on the potential, working principles, and small-scale applications of thermoelectric systems in converting motorcycle exhaust heat into electricity, particularly relevant to Indonesia's high motorcycle usage.

II. METHODS

This article employs a literature review approach, synthesizing data from 20 relevant scientific journals. A descriptive analysis method was used to examine secondary data, focusing on prior research findings rather than direct primary data collection. The objective is to analyze and present insights on the utilization of motorcycle exhaust heat for alternative electrical energy generation through thermoelectric components

III. RESULTS AND DISCUSSION

The energy Motorcycle exhaust systems generate substantial heat as a by-product of engine combustion. According to Lai et al., exhaust temperatures in motorcycles can range from 90°C to 250°C [9]. This level of heat represents a valuable energy resource that can be recovered through conversion into electrical energy using thermoelectric technology [10]. Thermoelectric devices produce electrical energy when there is a temperature difference between two sides of a semiconductor material, a phenomenon known as the Seebeck effect, the inverse of the Peltier effect. The Seebeck effect, first described by Thomas Seebeck in 1821,

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explains how a temperature gradient in a closed electrical circuit induces a voltage difference [11].

The working principle of the Seebeck effect is as follows: when one side of a thermoelectric module is exposed to heat (e.g., motorcycle exhaust) and the other side is cooled, electrons within the semiconductor material move from the hot side to the cold side. This movement generates a potential difference, producing electricity [12, 13]. Thermoelectric modules typically comprise N-type and P-type semiconductor materials arranged in series. These modules convert heat directly into electrical energy, offering durability and mechanical simplicity advantages. The output voltage and current are directly proportional to the temperature difference (ΔT) between the hot and cold sides. For example, a ΔT of 60°C can yield approximately 2.4 V and 0.469 A [14].

The direct current (DC) produced by thermoelectric can be used to power devices, but typically requires a converter to stabilize the voltage [15]. Ragil reported [16] that a series arrangement of thermoelectric modules installed on a motorcycle could produce 11.2 V and 122.1 mA at a speed of 40 km/h. This voltage was regulated before being stored in a battery. Similarly, Rosalina et al. reported that a single Peltier module produced 2.05 V, while two modules produced 2.46 V [17]. Although 2.05 V from one module may be insufficient to power a motorcycle's primary electrical system directly, it is adequate for small-scale uses such as powering a mini fan or charging a mobile phone, after voltage stabilization via a regulator [18].

Stored electrical energy can be distributed through a circuit system to achieve more stable power delivery. The number of thermoelectric modules installed also significantly affects total power output; more modules generally result in greater energy production [19]. Various studies have demonstrated that output performance depends not only on the number of modules but also on the temperature gradient across the modules and the overall heat transfer efficiency of the exhaust system.

Table 1. Comparative data of the research reviewed

Thermoelectric Types	Thermo electric Number	Vehicles	Power Generated	Ref
TEC1-12706	8	150cc sports motorcycle	36.15W	[20]
SP1848-27145	8	Motorcycle exhaust	≤9W	[14]
Leveraged TEG127-40A	3	Suzuki FXR 150cc	1.2W	[16]
-	16	Motorcycle exhaust	0.93W	[19]
TEC1-12706	Varies	Truck diesel engine	1.25kW	[21]
TE-MOD-10W4V-40	2	Motorcycle exhaust	4.2V	[8]
TEG12706	4	Diesel engine	17.01V, 15.49A	[22]

Table 1 highlights the thermoelectric generator (TEG) performance that varies significantly depending on the module type, number used, and vehicle type.. The number of thermoelectric modules installed directly influences the generated power; generally, more modules yield higher power output [23]. The average voltage and power values reported in the table are sufficiently high to be stored in a battery and subsequently distributed to motorcycle electrical components such as starters, lights, indicators, horns, and sensors. Typically, a motorcycle battery operates at 12 V to supply these components [24].

In addition to the number of thermoelectric modules, factors such as engine type and operating temperature significantly affect power generation. According to the Seebeck coefficient principle, a smaller temperature difference between the hot and cold sides of the thermoelectric element results in lower power generation, whereas a greater temperature difference produces higher output [25]. While much of the research focuses on motorcycles, thermoelectric technology can be applied to any vehicle that produces waste heat, such as cars, trucks, and buses [7]. For instance, car thermoelectric systems can utilize exhaust heat to improve overall fuel efficiency [26]. As shown in Table 1, studies by [21] and [27] reported higher power outputs when using diesel engines due to their higher exhaust temperatures.

Several studies have demonstrated practical small-scale applications of thermoelectric systems. Ragil reported that a voltage output sufficient to charge mobile phones via a voltage regulator is particularly beneficial for drivers who frequently use mobile devices, such as online motorcycle taxi operators [16]. A similar research was also reported by Naibaho and Tamba [28]. Similarly, Wardoyo achieved 36.15 W of power, which was used to power light electrical loads in vehicles, including LED lights, horns, and monitoring systems [20]. These findings collectively indicate that thermoelectric technology holds considerable potential for integrating waste heat recovery into vehicular systems, thereby supporting energy efficiency and sustainability.

The significant waste heat generated in vehicle exhaust systems and the widespread use of motorcycles in Indonesia present a promising opportunity for thermoelectric-based energy harvesting. By leveraging the Seebeck effect, thermoelectric devices can transform this otherwise lost heat into a usable and storable form of electrical energy. The integration of this technology not only supports sustainable energy initiatives but also offers practical benefits for vehicle owners, contributing to the broader goal of enhancing energy efficiency in transportation systems.

IV. Conclusion

The reviewed studies demonstrate that thermoelectric generators (TEGs) have significant potential for converting waste heat from vehicle exhaust systems into useful electrical energy. The output power is influenced by several factors, including the type and number of thermoelectric modules, the type of engine used, and the temperature difference between

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the hot and cold sides of the modules. Larger numbers of modules and greater temperature differences tend to produce higher electrical outputs, which can be effectively stored in batteries for powering various motorcycle or vehicle electrical components, such as starters, lights, indicators, and sensors. In specific applications, the generated power is sufficient to charge portable devices or operate auxiliary systems, offering practical benefits, especially for high-usage drivers. Furthermore, TEG technology is versatile and applicable to motorcycles, cars, trucks, and other vehicles, thereby supporting fuel efficiency and contributing to sustainable energy utilization.

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