Technological development in Thermoelectric Generators for Electric Vehicle Applications

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Abstract: *Thermoelectric generators (TEGs) are gaining popularity as a green power production alternative due to their ability to convert thermal energy into electric power through the Seebeck effect. TEGs are environmentally safe, quiet, and can be manufactured on various substrates. They are position-independent, long-lasting, and ideal for bulk and compact applications. This paper provides an in-depth analysis of TEGs, including their working principles, applications, materials, improvement techniques, and performance simulation examples. The increasing population, power costs, and global warming are causing scientists to improve energy harvesting efficiency. Waste heat recovery systems based on thermoelectric generators (TEGs) are being explored as an eco-friendly power source. This study introduces the integration of TEGs with other green power production technologies, discusses common materials used in TEG fabrication, and discusses applications in fuel cells, heat exchangers, photovoltaics, internal combustion engines, electric vehicles, and hybrid systems.*

INTRODUCTION:

When generating electricity in power stations, around two thirds of the energy is lost in the form of waste heat that's discharged from cooling halls The main reason is that the gas or brume- powered turbine systems, that operate to produce utmost of the electrical power, primarily function by burning energy to produce energy in the form of heat. This is followed by the conversion of this heat energy into mechanical energy within the turbine, and eventually turning the mechanical energy into electrical energy in a creator. As a result, only about1/3 of the energy released from the energy actually ends up in the transmission lines leaving the power factory.

The capability to collect the heat wasted within these processes and convert it to usable electrical power would tremendously increase the effectiveness of power generation. also, the reduction of hothouse emigration from the reduced destruction would be salutary for the terrain as lower energy is burned for the same quantum of electricity produced. In recent times, thermoelectric creator (TEG) systems have attracted great consideration in the recovery of waste heat due to their inimitable advantages TEGs give an occasion to induce electrical energy from heat energy without the need for moving corridor similar as turbines, which eliminates redundant costs performing from conservation and relief. TEGs have no economy scale- of effect and can be utilized for micro generation in a defined position or can be used to induce kilowatts. TEGs are also ecofriendly favorable as they operate smoothly without generating noise. Again, TEGs do have a low energy conversion effectiveness and bear a fairly constant heat source, which are disadvantages. TEGs can be used in multitudinous operations, similar as waste heat recovery and solar energy operation, experimental measures of solar thermoelectric creators with a peak effectiveness of9.6 and a system effectiveness of7.4 are reported by Kraemer et. al. was introduced in a study. A flexible thermoelectric creator using eutectic gallium indium liquid essence together with a high thermal conductivity elastomer was designed to gather body heat which can also be used for wearable electronics. A triadic micro combustor aimed at movable power generation was designed and developed to enhance heat transmission from hot feasts to thermoelectric modules vastly.

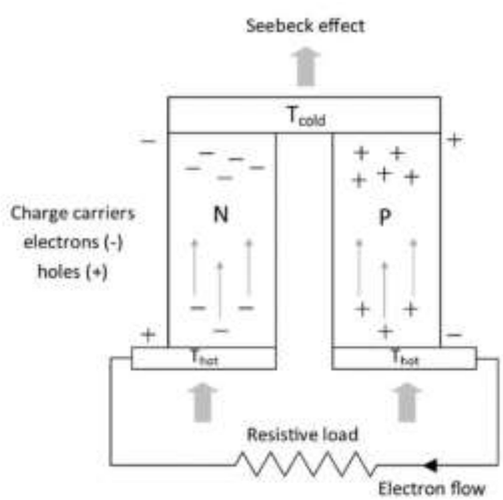

Fig. Thermoelectric Generation

The heat inflow direction in TEGs depends on thermocouples arrangements on the substrate. However, the heat will flow vertically, If the thermocouples are arranged vertically between the heat source and Gomorrah. still, if the thermocouples are arranged indirectly by publishing or depositing them on the substrate face, also the heat will flow in a side direction. Another arrangement is combining the side and perpendicular approaches. In this configuration the thermocouples will be also arranged indirectly on the substrate face, still, the heat inflow will be in the perpendicular direction with the aid of small depressions on the face of the substrate. Different thermocouple arrangements along with the heat inflow direction. There are many studies about the operation of the TEGs in waste heat recovery from different operations. This work summarizes the recent heat recovery methodologies and their operation in diurnal life systems grounded on TEGs. The review is composed of five sections including a preface. The alternate section deals with the fabrication and accoutrements of thermoelectric creators. The review goes beyond that by agitating colorful operations of TEGs waste heat recovery in energy cells, heat exchangers, photovoltaics, internal combustion machine, electric vehicles, and cold-blooded waste heat recovery systems, etc. In addition, the fourth section presents the walls and challenges of TEGs in waste heat recovery, while the fifth section is concerned about the conversations and conclusions.

Accoutrements used for fabrication of the thermoelectric creators (TEG) Different accoutrements and technologies are used to produce different designs of TEGs. Silicon technology grounded on reciprocal Essence Oxide Semiconductor – Integrated Circuits or reciprocal Essence Oxide Semiconductor – Micro Electromechanical Systems is used to produce small- scale TEGs. The generally used accoutrements in this system are Silicon, Germanium, Bismuth, and Antimony. Pottery- grounded technology is another technology that's used to produce high- viscosity multilayered TEGs. Thermocouples in this system can be fabricated via thin, thick, or mixed thin and thick deposit. Polymers material is used to manufacture flexible TEGs. The most applicable material for these kinds of technologies are polyimide, cellulose filaments- grounded, and Fabric. The material used to fabricate TEGs should be characterized by high affair voltage, high electrical power, and low internal resistance, in order to gain high electrical performance. The operation of TEGs covered large sectors that including electronic bias, machine machines, medical bias, and aerospace. Each operation requires a certain size and supplying power of TEGs. Consequently, TEGs, are classified as bulk or micro-TEGs. The bulk order are used for artificial operations, and it can supply up to hundreds of watts under a high heat range. The micro-TEGs order used for low waste heat and generates up to many mW. summarizes the graces and faults of the different TEG fabrication accoutrements

WORKING OPERATIONS OF TEG:

TEG systems consist of main three key elements

1. Thermoelectric modules
2. heat exchanger
3. heat sink

Waste heat recovery from energy cells: Energy cells are electrochemical bias that produce clean electricity and water as a derivate. They offer clean energy by the mean of simple electrochemical response (transfer of electrons and protons), no moving corridor, and high effectiveness (45 65). still, they induce a significant quantum of heat while producing electricity and this quantum of heat should be removed to avoid overheating. thus, the addition of thermoelectric creators (TEG) will help to minimize overheating inside the energy cell system while enhancing the overall effectiveness. Musharavati and Khan mohammadi performed an analysis for waste heat recovery for energy cells using a thermoelectric creator (TEG). In their study, a proton exchange membrane energy cell (PEMFC) and geothermal energy are integrated along with a TEG system. The performance analysis revealed an affair power of 3881 W which is 4 times advanced than the conventional compined heat and power (CHP) system. likewise, the study revealed18.56 and 40 of energy and exergy, independently, with a cost of0.27$/ GJ. likewise, Khan mohammadi et.al. performed a thermodynamic analysis of a concerted system conforming of a geothermal, PEMFC, and organic Rankine flash cycle (ORFC). The authors added two thermoelectric creators (TEGs) between each cooling palace and condenser. The results concluded that an enhancement of around 1 of the total effectiveness with involving TEG as a WHR compared to the conventional system as shown in Singh et.al. applied thermoelectric creator (TEG) to convert the waste heat generated from PEMFC (used to power a mini vehicle) into electricity. A dynamic cooling system to enhance the heat transfer in a PMFC- TEG system using curve inflow was created. The results demonstrated that the maximum power was increased by 15 times in the case of using curve conditions at 60 ◦C. likewise, a simulation using a 1 kW was performed by Kwan et.al., to enhance the measure of performance (Bobby) by recovering waste heat using TEG. The study revealed a1.1 improvement in the energy effectiveness under medium and reference temperatures of 10 ◦ C and 50 ◦ C, independently. The results concluded that operating at a tailwind of0.02 kg/ s revealed the stylish energy effectiveness. In a analogous study, Alam et. al. proposed a mongrel system for exercising waste heat from a 1 kW PEMFC conforming of TEG and 5 m3 essence hydride (MH) under two modes of cooling side TEG videlicet natural and addict cooling. Results revealed that heat loss was directly commensurable to the functional cargo which reflects on the TEG performance. likewise, a3.2 ◦ C maximum temperature difference was attained between the hot and cold ends. On the growing need to probe TEG models computationally and experimentally Mohamed et.al. delved experimentally and numerically the waste heat application from a 2 kW energy cell vehicle integrating TEG and a finned heat Gomorrah. The computational fluid dynamics was validated experimentally with only a 5 divagation. The results revealed a better waste heat recovery on the series configuration at lower speed; still, at advanced speed (100 km/ h) the resemblant configuration achieved a power1.5 times than that of the series.

FEASIBILITY OF INTEGRATING TEG PLATES IN ELECTRIC VEHICLES:

Integrating thermoelectric generator (TEG) plates in electric vehicles (EVs) is an intriguing concept with potential benefits but also challenges. TEGs generate electricity from the temperature difference between their hot and cold sides. In an EV, the heat generated by the engine or the exhaust system could be utilized to power TEGs, thus generating additional electricity to supplement the vehicle's power needs.

Feasibility considerations:

- Efficiency: TEG efficiency is a crucial factor. Traditional TEGs have relatively low efficiency, typically in the range of 5-10%. Advancements in materials science and TEG technology are improving efficiency, but it's still a concern.
- Cost: Cost-effectiveness is another major consideration. TEG materials, manufacturing, and integration costs need to be competitive with other power generation technologies.
- Size and Weight: TEG modules add weight and occupy space, which could affect the vehicle's performance and design. Ensuring that the benefits outweigh these drawbacks is essential.
- Integration: Integrating TEGs into the vehicle's exhaust system or other heat sources requires careful engineering to optimize heat transfer and minimize interference with other components.

- Heat Management: Efficient heat management is crucial for TEGs to operate effectively. Ensuring proper heat dissipation and minimizing thermal losses are significant challenges.
- Regulatory and Safety Compliance: Any new technology integrated into vehicles must meet regulatory and safety standards. This includes considerations for vehicle emissions, electrical safety, and overall performance.
- Environmental Impact: Assessing the environmental impact of TEGs, including their manufacturing process, materials used, and end-of-life disposal, is essential to ensure they align with sustainability goals.
- Scalability: TEG technology needs to be scalable to mass production levels to be viable for widespread adoption in the automotive industry.
- Performance Variation: TEG performance can vary based on operating conditions such as temperature gradients, which may not always be consistent in real-world driving scenarios.
- Battery vs. TEG Balance: Optimizing the balance between energy generated by TEGs and energy stored in batteries is critical to maximize overall efficiency and range.

VARIOUS THERMOELECTRIC MATERIALS AND THEIR SUITABILITY FOR TEG APPLICATIONS IN EVS:

Several thermoelectric materials are being researched and developed for various applications, including thermoelectric generator (TEG) systems in electric vehicles (EVs). These materials possess unique properties that make them suitable for different temperature ranges and environments. Few of promising thermoelectric materials include:

1. Bismuth Telluride (Bi2Te3): Bi2Te3 is one of the most widely used thermoelectric materials, particularly in commercial applications due to its relatively high thermoelectric performance near room temperature. It has good thermoelectric properties in the mid-temperature range, making it suitable for moderate heat differentials typically found in automotive exhaust systems.
2. Lead Telluride (PbTe): PbTe exhibits excellent thermoelectric properties at elevated temperatures, making it suitable for high-temperature applications. It can be used in TEGs to harness waste heat from the exhaust system of internal combustion engines or other high-temperature sources.
3. Silicon Germanium (SiGe): SiGe alloys offer a good balance between thermoelectric performance and compatibility with existing semiconductor manufacturing processes. SiGe-based thermoelectric materials can be tailored for specific temperature ranges, making them suitable for both low and moderate-temperature TEG applications in EVs.
4. Half-Heusler Alloys: Half-Heusler alloys, such as Ni-based or Ti-based compositions, exhibit good thermoelectric properties over a wide temperature range. They are being investigated for TEG applications in EVs, especially for capturing waste heat from various heat sources within the vehicle.

5. Organic and Polymer-based Materials: Organic and polymer-based thermoelectric materials are being explored for flexible and lightweight TEG applications, offering potential advantages in terms of low-cost fabrication and compatibility with curved surfaces.

ANALYSIS OF THE OVERALL ENERGY EFFICIENCY IMPROVEMENT ACHIEVED BY INCORPORATING TEG TECHNOLOGY:

The efficiency of TEGs is a crucial factor. Traditional TEGs have relatively low efficiency, typically in the range of 5-10%. However, advancements in materials science and TEG technology are improving efficiency. Higher efficiency TEGs would contribute more effectively to overall energy savings. The amount of waste heat available for harvesting varies depending on the vehicle's operation, driving conditions, and the specific heat sources targeted (e.g., exhaust, engine, braking system). Efficient TEG integration requires maximizing the utilization of waste heat without negatively impacting the vehicle's performance. Efficient integration of TEGs into the vehicle's systems is critical. Proper design and engineering are necessary to optimize heat transfer, minimize thermal losses, and ensure compatibility with other components. This integration may involve additional weight and complexity, which could impact overall vehicle efficiency. Assessing the overall energy efficiency improvement requires considering the entire lifecycle of TEG technology, including manufacturing, operation, and disposal. This analysis should account for energy inputs, emissions, and environmental impacts associated with TEG production and use. Real-world testing and validation are crucial for assessing the actual energy efficiency improvement achieved by TEG integration in EVs. Field trials and performance evaluations under varying driving conditions can provide valuable data for refining TEG systems and optimizing their efficiency. Optimizing the balance between energy generated by TEGs and energy consumed by other vehicle systems is essential. This includes balancing the energy harvested from waste heat with the energy required for TEG operation, auxiliary systems, and vehicle propulsion. Efficient energy management systems are needed to maximize overall energy efficiency. Comparing the energy efficiency improvement achieved by incorporating TEG technology with alternative energy recovery and generation systems is essential. This includes evaluating the efficiency, cost-effectiveness, and environmental impact of TEGs relative to other technologies such as regenerative braking, photovoltaics, and battery storage systems.

CONCLUSION:

Thermoelectric generators (TEGs) for electric vehicles are making significant strides towards sustainable and efficient energy solutions in transportation. These advancements harness waste heat from electric vehicles, turning it into a valuable resource for electricity generation. As TEG designs, materials, and integration methods refine, they contribute to environmental sustainability and energy efficiency. These developments offer prospects for reducing dependence on conventional energy sources, decreasing greenhouse gas emissions, and mitigating the environmental impact of transportation. The interdisciplinary nature of sustainable technology, involving materials science, engineering, and automotive technology, is evident in the ongoing research and innovation in TEGs. While challenges like cost-effectiveness and scalability remain, the trajectory of technological advancements suggests a bright future for TEGs in electric vehicles. As these technologies mature and become commercially viable, they could play a pivotal role in shaping a cleaner, greener, and more energy-efficient future for the transportation sector.

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