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THERMO ELECTRIC GENERATOR FOR ENERGY EFFICIENCY IN MARINE VESSELS

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1-ABSTRACT-*This journal presents a detailed investigation of the use of thermoelectric generators (TEGs) for energy recovery on marine ships, focusing on converting waste heat from engines and exhaust systems into usable electrical power. Thermoelectric generators use the Seebeck effect to generate electricity from a temperature gradient, making them suitable for marine applications with high waste heat generation. The study investigates the design, installation and performance of a TEG prototype on a ship engine, as well as its impact on fuel consumption and emissions. The results show that TEGs provide measurable fuel savings and emission reductions, although with challenges related to efficiency, cost and durability in the marine environment. Future recommendations for TEG integration in the marine industry are provided, highlighting potential improvements in thermoelectric materials and system design.*

KEYPOINTS

1. Objective: To explore the feasibility of using thermoelectric generators (TEGs) to convert waste heat into electricity on marine ships, thereby increasing energy efficiency and reducing fuel consumption.

2. Technology: TEGs operate on the Seebeck effect, generating electrical power from temperature differences, which is ideal for capturing waste heat from ship engines and exhaust systems.

3. Prototype installation: A TEG prototype was installed on the ship's exhaust system, using bismuth telluride modules to withstand the high temperatures typical of marine engines.

4. Energy generation: The prototype generated an average of 5 kW of electricity, with a maximum output of up to 6 kW, reducing fuel usage by approximately 1%.

5. Environmental impact: The TEG system reduced ship emissions by capturing energy that would have otherwise been lost, thereby contributing to reduced CO_2, NOx and SOx outputs.

6. Economic Feasibility: Despite the high initial installation cost, the system has proven to be economically beneficial over time through fuel savings, especially in ships sailing continuously.

2- INTRODUCTION

Thermoelectric generators (TEGs) exploit temperature differences to convert heat directly into electricity, a process that is valuable for applications with abundant waste heat, such as marine vessels. The marine industry is constantly seeking solutions to reduce fuel consumption and emissions, making waste heat recovery systems such as TEGs a promising option for improving energy efficiency. This journal covers TEG technology's feasibility, design considerations and implementation in marine vessels.

3. BACKGROUND AND THEORY

TEGs operate on the Seebeck effect, where a temperature gradient across two dissimilar materials generates an electric voltage. The efficiency of a TEG system depends on the thermoelectric material, the temperature gradient, and the system design. Bismuth telluride (Bi_2Te_3) modules, known for their high efficiency in the moderate temperature range, are commonly used in TEG systems and were chosen for the vessel prototype discussed in this study

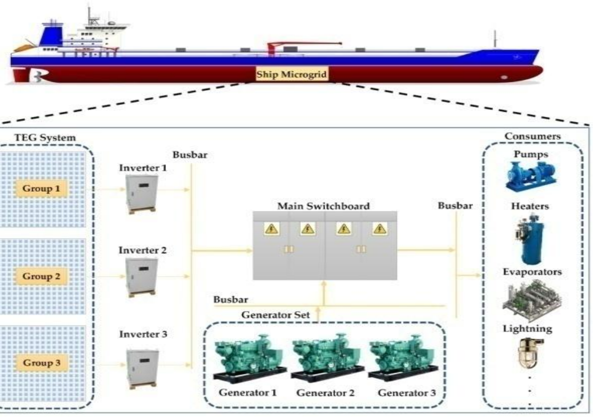

Fig No 1: Ship Microgrid with Thermoelectric Generator (TEG) System Architecture

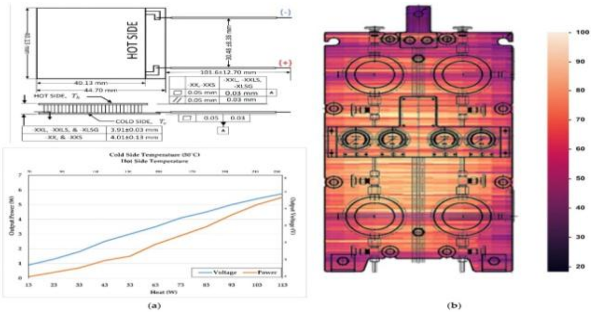

Fig No 2: TEG Heat Exchanger Thermal Analysis and Temperature Distribution

4. PROJECT OBJECTIVES

The aim of the study was to:

Evaluate the potential of TEG to harness waste heat on marine vessels.

Assess the energy production, fuel savings and emission reduction of the system.

Identify design and operational challenges specific to the marine environment.

5. METHODOLOGY

A prototype TEG system was installed on a 2000 kW diesel-powered vessel, placed near exhaust systems with high temperature gradients. The system was equipped with:

Thermoelectric modules: Bismuth telluride modules for high performance in targeted temperature ranges.

Heat exchangers: Custom-designed to maximize heat transfer.

Power conditioning: A DC-DC converter stabilizes the output, making it compatible with onboard electrical systems.

Temperature sensors monitored the gradient across the TEG modules, and output power was recorded under various engine loads. The durability of the system was also evaluated in a real-world marine environment exposed to vibration, salt water, and exhaust particles.

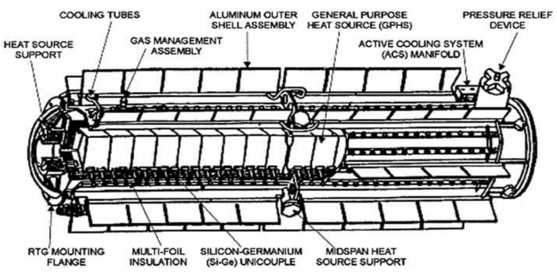

Fig No 3: Thermoelectric Generator (TEG) Operating Principle Based on the Seebeck Effect

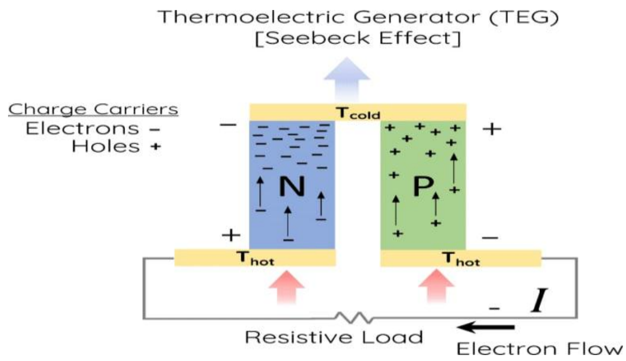

Fig No 4: Internal Construction of a Radioisotope Thermoelectric Generator (RTG)

Results and Analysis

5.1 Power Output and Efficiency

The TEG system achieved an average output of 5 kW, with a peak of 6 kW at high engine load, providing approximately 0.25% of the ship's total power needs. The system's efficiency, while lower than other power generation technologies, demonstrates the potential for fuel savings over long periods of operation.

5.2 Environmental and Economic Impacts

Fuel savings averaged approximately 1%, resulting in reduced CO2, NOx and SOx emissions. Economic analysis indicated that, despite high initial installation costs, system savings could offset costs over time, especially for ships with high operating hours.

5.3 Durability

The TEG modules demonstrated durability against marine vibration and saltwater corrosion, although some degradation of supporting materials was observed. Maintenance requirements were minimal, but ongoing durability improvements are recommended.

DISCUSSION

This study confirms that TEGs can contribute to energy efficiency and emission reduction in marine vessels. However, challenges related to conversion efficiency, system cost and the harsh marine environment must be addressed for widespread adoption. Key discussion points include:

Material advancement: More robust and efficient thermoelectric materials are needed to improve power output and durability.

System design: Compact, corrosion-resistant designs that integrate with existing vessel systems are essential.

Economic feasibility: While promising, TEG systems must become more affordable to see widespread implementation in the marine industry.

6. Challenges and limitations

Low efficiency: TEG's relatively low conversion efficiency means that only a small portion of the waste heat is recovered.

High initial cost: TEG materials, especially in corrosion-resistant configurations, are expensive.

Location and integration: Implementing a TEG system requires adequate space and careful integration with the vessel's power system, which can be challenging in older or space-limited vessels

7. Environmental and economic impact

The integration of TEG on ships has a positive impact on the environment, as it reduces the need for additional fuel consumption by harnessing waste heat. By capturing even a small portion of waste heat, ships can save fuel and reduce CO_2, NO_x and SO_x emissions. Economic analysis showed that although the initial installation cost was high, the system could pay for itself over time through fuel savings, especially for ships that operate for long periods of time

Fig No 5: Ship Exhaust Emissions and Waste Heat Source for Thermoelectric Power Generation.

8. FUTURE WORK

Further research is needed to optimize TEG system designs for different types of ships and operating conditions. Additionally, long-term testing and durability studies will help understand the lifetime and maintenance needs of TEGs in the marine environment. Power generation and efficiency can also be maximized by implementing advanced control systems to adjust TEG operation based on ship load conditions.

This report outlines the potential of TEG technology to improve ship efficiency, with current limitations. With ongoing advances in thermoelectric materials and system integration, TEGs may become an increasingly viable energy solution in the marine industry.

9.CONCLUSION:

This project demonstrates the potential of thermoelectric generators (TEGs) to increase energy efficiency on marine vessels by converting waste heat into electricity. The prototype TEG systems produced an average of 5 kW of electricity, saving approximately 1% of fuel and reducing emissions such as CO_2, NO_x and SO_x. Although current TEG technology has limitations in terms of low conversion efficiency, high initial cost and challenges with durability in marine environments, these systems offer long-term environmental and economic benefits, especially for ships that operate continuously.

The successful operation of the prototype shows that TEGs can play an important role in improving ship efficiency. For widespread adoption, advances in thermoelectric materials,design optimization for marine durability and possible hybridization with other energy recovery systems are recommended. With continued development, TEG technology can support the maritime industry's goals of reducing fuel consumption and emissions, contributing to a more sustainable future in marine operations

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