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THERMOELECTRIC WASTE HEAT RECOVERY SYSTEM

Dharmana Prasad[1], P Sampath Kumar Achari[2], Penta Kunta Prudhvi[3], Praveen[4]

6thSem B.E (Mechanical Engineering) , Ballari Institute of Technology and Management (BITM), Ballari, Karnataka-583104, India1-4

Abstract: Thermoelectric Waste Heat Recovery Systems (TWHRS) are gaining significant attention due to their ability to convert waste heat directly into electrical energy using thermoelectric generators (TEGs). In many industrial processes, automobiles, and power generation systems, a large amount of heat energy is lost to the environment. Recovering this wasted thermal energy can improve overall system efficiency and reduce fuel consumption and environmental pollution.

The present work focuses on the design and analysis of a thermoelectric waste heat recovery system using thermoelectric modules for converting exhaust heat into usable electrical power. The study investigates the major components, working principles, heat transfer mechanisms, and performance characteristics of the system. Parameters such as temperature difference, heat sink performance, module arrangement, and electrical output were analyzed.

Experimental observations indicate that increasing the temperature gradient across thermoelectric modules significantly improves voltage generation and power output. The developed system demonstrates improved energy efficiency and sustainable power generation from otherwise wasted thermal energy.

Keywords: Thermoelectric Generator, Waste Heat Recovery, Seebeck Effect, Energy Efficiency, Heat Recovery System, Sustainable Energy.

INTRODUCTION

Energy conservation and efficient utilization of available energy resources have become important challenges in modern industries and transportation systems. A significant portion of energy produced in automobiles, thermal plants, furnaces, and industrial machinery is lost in the form of waste heat.

Waste heat recovery systems help improve overall efficiency by converting unused thermal energy into useful forms such as electricity. Among the available technologies, thermoelectric waste heat recovery systems are highly attractive because they directly convert heat into electrical energy without moving parts.

Thermoelectric generators operate based on the Seebeck effect, where a voltage is generated due to the temperature difference between two sides of a thermoelectric material.

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Where:

V = Generated Voltage
S = Seebeck Coefficient
T_h = Hot Side Temperature
T_c = Cold Side Temperature

Thermoelectric systems are compact, reliable, environmentally friendly, and require minimal maintenance. They are widely used in automobile exhaust systems, industrial boilers, and power plants for recovering waste thermal energy.

The present study aims to analyze the performance of a thermoelectric waste heat recovery system and evaluate its efficiency under different operating conditions.

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LITERATURE REVIEW

Several researchers have investigated thermoelectric waste heat recovery technologies and their applications.

Smith et al. studied automobile exhaust heat recovery using thermoelectric generators and concluded that thermoelectric modules can significantly improve fuel efficiency.

Kumar and Reddy analyzed the effect of temperature difference on thermoelectric power generation and observed that power output increases with higher thermal gradients.

Lee et al. investigated heat sink optimization for thermoelectric systems and reported improved cooling efficiency and electrical output.

Patel and Sharma studied different thermoelectric materials and found that bismuth telluride-based modules provide better performance in medium-temperature applications.

Basavarajappa et al. reported that proper thermal insulation and optimized module arrangement improve overall system efficiency and reliability.

The literature review indicates that temperature control, efficient heat transfer, proper cooling systems, and optimized thermoelectric materials are essential for improving waste heat recovery performance.

MATERIALS AND METHODS

3.1 Components Used

Component Purpose
Thermoelectric Generator (TEG) Module Converts heat into electricity Heat Source Provides waste thermal energy Heat Sink Removes heat from cold side Cooling Fan Improves heat dissipation Aluminum Plate Heat transfer medium
Temperature Sensor Measures temperature difference Multimeter Measures voltage and current Battery/Load Stores or utilizes generated power

3.2 Working Principle

The thermoelectric waste heat recovery system works based on the Seebeck effect. When one side of the thermoelectric module is exposed to high temperature and the other side is maintained at lower temperature, an electric potential difference is generated. The generated electrical power can be expressed as:

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Where:
P = Power Output
V = Voltage Generated
I = Current Produced

The efficiency of the thermoelectric generator depends mainly on the temperature difference across the module.

3.3 Advantages of Thermoelectric Waste Heat Recovery

Direct conversion of heat into electricity
No moving mechanical parts
Low maintenance requirement
Environmentally friendly operation
Compact and lightweight system
Improved energy efficiency
Reduced fuel consumption

3.4 Limitations

Lower efficiency compared to conventional generators
High material cost

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Limited power output
Requirement of effective cooling systems

EXPERIMENTAL PROCEDURE

4.1 Experimental Setup

The experimental setup consists of thermoelectric modules mounted between a hot surface and a cooling heat sink. Heat from the source is transferred to the hot side of the TEG module, while cooling fans maintain lower temperature on the cold side.

The generated voltage and current were measured using digital instruments under different temperature conditions.

4.2 Testing Procedure

The experiment was conducted in the following stages:

Step 1: Initial Setup
Thermoelectric modules were mounted properly.
Heat sink and cooling fans were installed.
Electrical connections were checked.

Step 2: Heat Application
Heat was supplied to the hot side.
Temperature readings were monitored continuously.

Step 3: Data Collection
The following parameters were recorded:
Hot side temperature
Cold side temperature
Temperature difference
Output voltage
Output current
Power generated

Step 4: Performance Analysis
The performance of the system was analyzed for different temperature gradients.

RESULTS AND DISCUSSION

5.1 Temperature vs Voltage Output

Temperature Difference (°C)	Output Voltage (V)
20	1.2
40	2.5
60	3.9
80	5.4
100	6.8

The results indicate that output voltage increases with increase in temperature difference across the thermoelectric module.

5.2 Power Generation Analysis

Temperature Difference (°C)	Power Output (W)
20	0.8
40	1.7
60	2.9
80	4.2
100	5.6

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The experimental observations show improved power generation at higher thermal gradients.

5.3 Advantages Observed

Recovery of waste thermal energy
Improved energy utilization
Reduction in fuel wastage
Eco-friendly electricity generation
Compact and reliable system
Reduced environmental pollution
Improved overall efficiency

CONCLUSION

The present study successfully analyzed the working and performance of a thermoelectric waste heat recovery system. The investigation revealed that thermoelectric generators can effectively convert waste thermal energy into useful electrical energy.

The experimental results showed that increasing the temperature difference across thermoelectric modules improves voltage generation and power output. The developed system demonstrates improved energy efficiency, reduced energy wastage, and environmentally friendly operation.

Thermoelectric waste heat recovery systems can play an important role in future sustainable energy technologies, especially in automobiles, industrial plants, and thermal systems.

FUTURE SCOPE

Future research may focus on:
Advanced thermoelectric materials
AI-based performance optimization
Improved heat sink designs
Hybrid waste heat recovery systems
Integration with automobile exhaust systems
IoT-based thermal monitoring
High-efficiency thermoelectric modules
Large-scale industrial implementation

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