Development of Power Generation from Waste Heat in Industries using Thermoelectric Generator

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***Abstract*—** The rapid growth of industries and transportation has increased energy demand and also produced a large amount of waste heat that is usually released into the environment. This unused heat represents a significant loss of energy and contributes to environmental pollution. The present study focuses on the **development of a power generation system from industrial waste heat using a Thermoelectric Generator (TEG)**. A thermoelectric generator is a solid-state device that converts heat energy directly into electrical energy based on the **Seebeck effect**, where a temperature difference across two dissimilar materials generates a voltage. In the proposed system, waste heat produced by industrial machinery or exhaust gases acts as the hot side of the TEG module, while a heat sink maintains a cooler temperature on the opposite side. The temperature difference between these two sides generates electrical power. The produced electricity is measured using sensors and can be stored in a battery for further use. A microcontroller with an LCD display is used to monitor voltage and temperature levels in the system. The generated power can be used for small loads such as fans, lighting, and monitoring devices. The system provides a clean, reliable, and environmentally friendly method for utilizing waste heat and improving overall energy efficiency in industrial applications.

Keywords: *Thermoelectric Generator (TEG), Waste Heat Recovery, Seebeck Effect, Industrial Energy Efficiency, Power Generation etc.*

I. INTRODUCTION

Energy plays a vital role in the development of modern industries and transportation systems. With the continuous growth of industrial production and technological advancements, the demand for energy is increasing rapidly. At the same time, conventional energy resources such as coal, petroleum, and natural gas are limited and contribute significantly to environmental pollution. Therefore, there is an urgent need to develop alternative methods that improve energy efficiency and utilize available resources more effectively. One of the most promising approaches to achieve this objective is waste heat recovery.

In many industrial processes and mechanical systems, a large portion of input energy is lost in the form of heat. Internal combustion engines, furnaces, boilers, and various industrial machines release a significant amount of heat through exhaust gases and cooling systems. Studies indicate that only 30–40% of the fuel energy in internal combustion engines is converted into useful mechanical work, while the remaining energy is dissipated as waste heat. This unused heat not only reduces the overall efficiency of the system but also contributes to environmental pollution. If this waste heat can be recovered and converted into useful energy, it can significantly improve the energy efficiency of industrial systems.

One of the advanced technologies used for converting waste heat into electrical energy is the Thermoelectric Generator (TEG). A thermoelectric generator is a solid-state device that converts thermal energy directly into electrical energy using the Seebeck effect. The Seebeck effect states that when there is a temperature difference between two junctions of dissimilar semiconductor materials, an electrical voltage is generated. A typical thermoelectric module consists of multiple pairs of p-type and n-type semiconductor elements connected electrically in series and thermally in parallel. When one side of the module is exposed to a high temperature (hot side) and the other side is maintained at a lower temperature (cold side), charge carriers move from the hot side to the cold side, producing an electric current.

Thermoelectric generators offer several advantages compared to conventional power generation technologies. They have no moving parts, operate silently, require minimal maintenance, and have a long operational life. In addition, they are compact, environmentally friendly, and capable of operating in harsh environments. These features make TEGs suitable for applications such as waste heat recovery in industries, automotive exhaust systems, space power systems, and remote power generation.

In this project, a thermoelectric generator system is developed to utilize waste heat from industrial machinery or engine exhaust gases to generate electrical energy. The system consists of thermoelectric modules, heat sinks, temperature sensors, a battery storage system, and a microcontroller-based monitoring unit. The heat from the industrial source acts as the hot side, while a cooling arrangement maintains the cold side of the module. The generated electrical energy is stored in a battery and can be used to power small electrical loads such as fans, lights, and monitoring devices.

The proposed system aims to demonstrate an efficient method of converting unused thermal energy into useful electrical power. By implementing such systems in industries, it is possible to reduce energy losses, lower operational costs, and contribute to environmental sustainability. Waste heat recovery using thermoelectric generators therefore represents a promising step toward improving energy utilization and developing sustainable energy solutions.

II. PROBLEM IDENTIFICATION

- A large amount of heat energy produced in industries and internal combustion engines is released into the environment without being utilized, resulting in significant energy loss.
- Most industrial machines operate continuously and generate exhaust heat through pipes, boilers, furnaces, and engines, which is usually dissipated into the atmosphere.
- The low efficiency of conventional systems, where only about 30–40% of fuel energy is converted into useful work, leads to a major portion of energy being wasted as heat.
- The release of waste heat contributes to environmental problems such as increased thermal pollution and greenhouse gas emissions.
- Industries rely heavily on conventional energy sources like coal, diesel, and electricity, which increases operational costs and energy demand.
- Existing waste heat recovery systems are often complex, expensive, and require mechanical moving parts, making them difficult to maintain.
- There is a need for a simple, reliable, and low-cost system that can convert waste heat directly into electrical energy.
- Thermoelectric generators provide a potential solution for efficient waste heat recovery and small-scale power generation in industrial environments.

III. LITERATURE REVIEWS

A) Literature Survey:

He et al., 2023, The study investigated the application of thermoelectric generators for recovering waste heat from industrial exhaust systems. The researchers analyzed the thermal performance and power generation capability of TEG modules installed on high-temperature exhaust pipes. Results indicated that significant electrical power can be generated when a large temperature gradient is maintained between the hot and cold sides of the module. The study also highlighted the importance of proper heat sink design to maintain cooling efficiency. It concluded that TEG systems can improve industrial energy efficiency and reduce energy loss by converting unused thermal energy into usable electrical power.

Liu et al., 2022, This research analyzed the performance of thermoelectric generators installed on internal combustion engine exhaust systems. The authors conducted experimental testing to evaluate voltage generation under different temperature conditions. The results showed that the electrical output of TEG modules increases significantly with temperature difference across the module. The study also examined different thermoelectric materials to improve conversion efficiency. It was observed that optimized module placement and improved thermal contact enhance power generation. The research concluded that TEG technology is a promising method for converting waste heat into electricity in automotive and industrial applications.

Kumar and Singh, 2024, The authors developed an experimental setup to generate electricity from industrial waste heat using thermoelectric modules. The study measured voltage and current output at various temperature levels. The results showed that electrical power generation increases with higher temperature differences between the hot and cold sides. The system was able to generate small-scale electrical power sufficient for charging batteries and operating small electronic devices. The research emphasized that connecting multiple TEG modules in series or parallel can significantly increase power output. The study concluded that thermoelectric systems are suitable for small-scale renewable energy applications.

Zhang et al., 2021, This study focused on utilizing exhaust heat from automobiles for electrical power generation using thermoelectric generators. The authors developed a TEG module arrangement installed along the exhaust pipe of a vehicle engine. Experimental results demonstrated that a temperature difference of more than 150°C could generate considerable electrical power. The research also evaluated the effect of airflow and cooling mechanisms on system efficiency. The findings suggested that integrating thermoelectric generators with vehicle exhaust systems can improve overall fuel efficiency and reduce energy loss.

Patel et al., 2023, The study investigated the feasibility of installing thermoelectric generators on industrial boilers to recover waste heat energy. The researchers analyzed temperature profiles around boiler exhaust systems and designed a thermoelectric module arrangement for optimal energy conversion. The results showed that the system could generate sufficient electrical power to operate monitoring sensors and low-power devices. The research highlighted the importance of maintaining effective cooling on the cold side of the module to improve efficiency. The study concluded that

TEG systems can contribute to energy savings and reduce operational costs in industrial environments.

Chen et al., 2022, This research focused on optimizing the design parameters of thermoelectric generators for improved power generation. The authors examined factors such as module configuration, heat transfer rate, and cooling efficiency. Simulation and experimental results indicated that optimizing the thermal interface and using advanced thermoelectric materials significantly improves output performance. The study found that higher temperature gradients lead to increased voltage generation. It concluded that design optimization and material improvements are essential to enhance the efficiency of thermoelectric waste heat recovery systems.

Sharma and Gupta, 2021, The research explored the use of thermoelectric modules for converting waste heat from engine exhaust systems into electrical power. The experimental system included TEG modules mounted on the exhaust pipe and connected to a battery storage unit. The results demonstrated that the system could generate stable electrical output under continuous operation. The generated electricity was sufficient to power small electrical loads such as LED lights and cooling fans. The study concluded that thermoelectric technology offers an efficient method for utilizing waste heat and improving overall system energy efficiency.

Rahman et al., 2024, The authors investigated energy harvesting techniques using thermoelectric generators in industrial environments. The study focused on recovering heat from industrial machinery and converting it into electrical energy. Experimental analysis showed that the efficiency of TEG systems depends heavily on the temperature gradient and material properties of the thermoelectric modules. The researchers also analyzed different cooling techniques to maintain the cold side temperature. The results indicated that TEG systems can generate sustainable electricity and improve energy utilization in industrial systems.

Park et al., 2023, This study analyzed thermoelectric generator performance under high-temperature industrial conditions. The researchers tested different thermoelectric materials capable of operating at temperatures above 400°C. Results showed that high-temperature thermoelectric materials significantly improve power generation efficiency. The study also emphasized the importance of thermal stability and proper heat management for long-term operation. The authors concluded that advanced thermoelectric materials can enhance waste heat recovery systems in heavy industrial processes.

Singh et al., 2022, This research developed a prototype thermoelectric power generation system designed for industrial waste heat recovery. The system included thermoelectric modules, heat sinks, temperature sensors, and a microcontroller-based monitoring system. Experimental results showed that the generated voltage increases proportionally with temperature difference. The prototype demonstrated the capability of generating electrical power for battery charging and small electronic devices. The study concluded that thermoelectric generators provide an effective solution for converting waste heat into electrical energy and improving industrial energy efficiency.

IV. RESEARCH METHODOLOGY

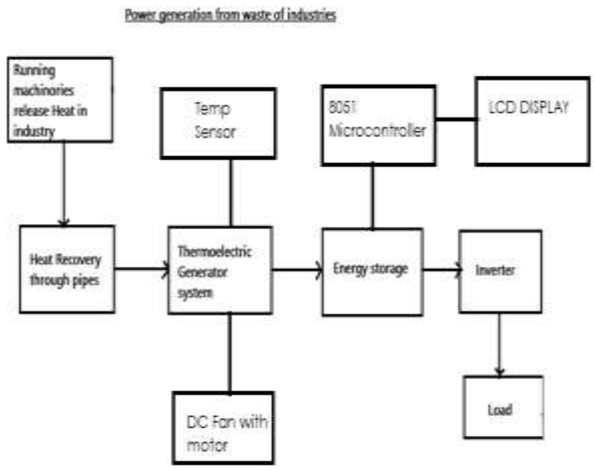


Fig.1.Proposed System

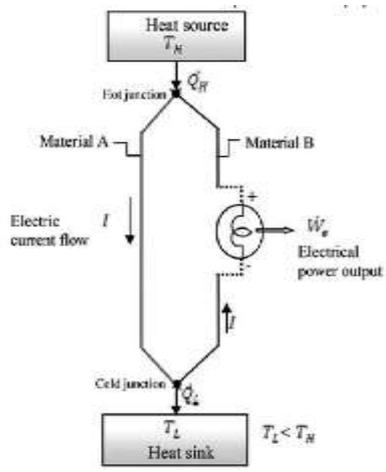


Fig.2.Working Principle

TEG consists of one hot side and one cold side. The hot side with higher temperature, will drive electrons in the n-type leg toward the cold side with lower temperature, which cross the metallic interconnect, and pass into the p-type leg, thus developing a current through the circuit.
If temperature difference is kept constant, then the diffusion of charge carriers will form a constant heat current, hence a constant electrical current.

Working :

- Non-conventional energy using is converting mechanical energy into the electrical energy. Here in this project a power generation arrangement is made. Use of thermoelectric principle makes this system efficient and reliable.
- In any industry machineries continuously run for their production. It release large amount of heat. This is wastage heat. We utilized this wastage heat to produce electricity. In this way we can minimize some amount air pollution also.
- When we apply TEG with Heat sink module to wastage heat through heat pipe executed from machine. Then at the same time TEG starts converting Heat energy into Electrical energy. We can measure this heat with the help of temperature sensor attached to the system.
- One DC fan is attached to system to indicates the flow and conversion of heat energy into Electrical energy. As the amount of temperature is increases, the flow of fan is also increases.

- Generated electrical energy is stored in battery. This stored energy is supply to inverter to convert DC to AC.
- At the output AC load is obtain. This AC load is utilized to run various loads in same industry like, fan, AC , light etc.
- We also attached 8051 microcontroller (AT89S52) with LCD display to measure the amount of voltage stored and remaining in battery.
- In this way, whole system work. Start from wastage of heat dissipated in industry through production process. Then conversion of heat into electricity. Indication of conversion electricity through DC fan and motor. Storage of electricity in battery. Conversion of DC voltage to AC voltage with help of inverter. Microcontroller attached to show the voltage present at battery. And last AC load attached to inverter.
- If such system utilized in automobiles industry, the amount of wastage heat we can utilized it. And also minimized air pollution problem cussing by vehicles.

Components Specification :

- Thermoelectric plate
- Exhaust fan with Aluminum heat sink
- Silencer
- Heat source (Engine considered device)
- DC motor with fan
- Battery
- Inverter module
- Temperature sensor
- Controller board (8051 controller)
- LCD display (16*2)
- wiring
- switches
- LED bulb
- Metallic Frame
- connector circuit board
- Adapter

Necessity Of TEG (Thermo Electrical Generator):

- TEGs are solid-state device, which means that they have no moving parts during their operations. Together with features that they produce no noise and involve no harmful agents, they are the most widely adopted devices for waste heat recovery.

- Useful electricity generation is possible due to the great amount of waste heat emitted from I.C. engine operation.

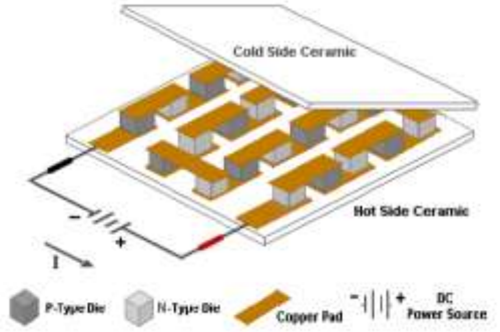


Fig.3.Internal construction of thermo- electric module

Power Generation in Peltier Plate by Seebeck Effect: Seebeck found that if you placed a temperature gradient across the junctions of two dissimilar conductors, electrical current would flow. The effect is shown below in the Fig.

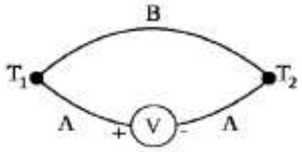


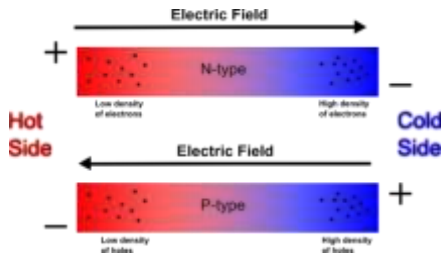
Fig.4.Seeback effect

The main focus of energy conversion is on three conversion locations mainly exhaust gas pipe (EGP), exhaust gas recirculation (EGR) cooler, and retarder. The most significant factors for the waste heat quality are power density and temperature range.

The EGP is the target of the most industries waste heat recovery related research. The exhaust system contains a large portion of the total waste heat in industries. The gas flow in exhaust gas pipe is relatively, stable. Fig. shows that TEG utilizing the exhaust gas heat for operation. With exhaust temperatures of 973 K or more, the temperature difference between exhaust gas on the hot side and coolant on the cold side is close to 373 K. This temperature difference is capable of generating 10W of electricity.

CAD Model :

- **Inside Peltier Plate**



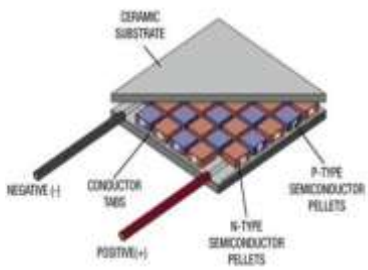


Fig.5. Thermoelectric Generator System

V. BENEFITS

- TEGs are solid-state device, which means that they have no moving parts during their operations. No moving parts so maintenance required is less frequently, no chlorofluorocarbons. Temperature control to within fractions of a degree can be maintained, flexible shape, very small size.
- TEGs can be used in environments that are smaller or more severe than conventional refrigeration. TEG has long life, and also it can be controllable by changing the input voltage/current.

VI. SCOPE OF THE STUDY

- By using thermoelectric generator connecting in series /parallel we can generate the power for maximum level
- Even body heat also generate the heat that can be utilizing by using TEG to generate the power to charge the portable equipment like laptop mobile etc
- By installed in the vehicle above the radiator means the vehicle battery will charge self.

VII. ADVANTAGES

- Clean, Noise less , Cost is less .
- This is a Non-conventional system ,No fuel is require
- Easy maintenance, portable, Charging time is less (maximum temp)
- Promising technology for solving power crisis to an affordable extent.
- Simple in construction, Pollution free, Reduces transmission losses.
- Wide areas of application# Required less space
- It can be use at any time when it necessary.
- Less number of parts required.
- we can charge any electronic devices
- Electricity can used for many purposes
- Efficient and eliminate the grid searching.

VIII. APPLICATIONS

- Thermoelectric Generators are basically used in where the power production is less.
- In many industries amount of heat is executed and been wastage. We can used this hear for electricity using TEG.
- In automobile vehicle produce heat that can be used for generating electricity by using TEG.
- Recharge the battery where ever waste heat is obtained.
- Self charging battery by fixing the TEG at radiator or two wheeler silencers pipe.

IX. RESULT AND DISCUSSION

Benefits of 'waste heat recovery' can be broadly classified in two categories

1. Direct Benefits:

Recovery of waste heat has a direct effect on the combustion process efficiency. This is reflected by reduction in the utility consumption and process cost.

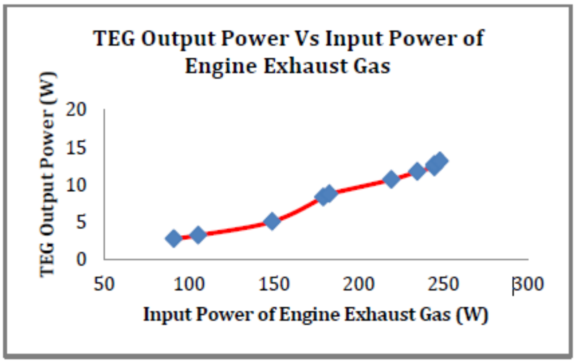
2. Indirect Benefits:

a) Reduction in pollution: A number of toxic combustible wastes such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) etc, releasing to atmosphere. Recovering of heat reduces the environmental pollution levels.
b) Reduction in equipment sizes: Waste heat recovery reduces the fuel consumption, which leads to reduction in the flue gas produced. This results in reduction in equipment sizes.
c) Reduction in auxiliary energy consumption: Reduction in equipment sizes gives additional benefits in the form of reduction in auxiliary energy consumption.
The experimental results obtained are tabulated as follows:

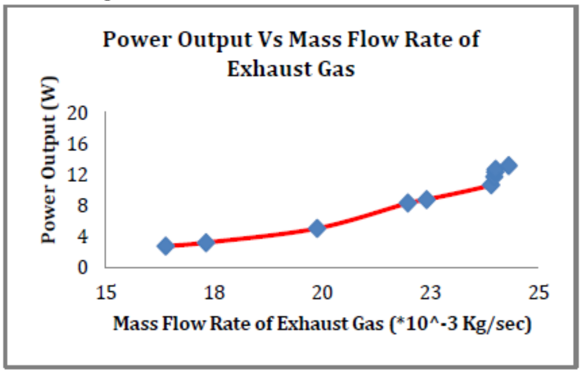
Table 1: Voltage generated and boosted for different temperatures

Temperature difference δt (k)	Voltage without boosting (volt)	Voltage after boosting (volt)
80	0.02296	1.44
100	0.02870	2.53
120	0.03444	3.21
140	0.04018	3.85
150	0.04305	4.43
160	0.04592	4.94
180	0.05166	5.37
200	0.05740	6.10

TEG Output Power Vs Input Power of Exhaust heat Gas



Power Output Vs Mass Flow Rate of Exhaust Heat Gas



- The graph shows that the power output is function of mass flow rate of exhaust gas. At the mass flow rate of exhaust gas of 24.317 Kg/sec. the power developed by TEG system is average 10 W.

- Waste heat recovery entails capturing and reusing the waste heat from internal combustion engine and using it for heating or generating mechanical or electrical work. It would also help to recognize the improvement in performance and emissions of the engine if these technologies were adopted by the automotive manufacturers.

X. CONCLUSION

The development of a power generation system using a Thermoelectric Generator (TEG) demonstrates an effective method for utilizing waste heat produced in industrial processes and machinery. A large amount of thermal energy generated in industries is normally released into the atmosphere without being used, which results in energy loss and environmental pollution. The proposed system successfully converts this unused heat energy into useful electrical power using the thermoelectric principle based on the Seebeck effect.

In this project, the temperature difference between the hot side and cold side of the thermoelectric module produces electrical voltage that can be used to operate small loads or stored in a battery for later use. The use of sensors, microcontroller, and display units helps in monitoring the temperature and generated voltage efficiently. The system is simple in construction, reliable in operation, and requires very low maintenance due to the absence of moving parts.

Although the power generated from a single module is relatively small, multiple thermoelectric modules can be connected together to increase the output power. Therefore, the proposed thermoelectric generator system provides a clean, eco-friendly, and sustainable solution for waste heat recovery and efficient energy utilization in industries.

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