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Generating Electrical Energy Using Biogas with Peltier Effect

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Abstract: The project "Generating Electrical Energy Using Biogas with Peltier Effect" focuses on producing renewable electricity from organic waste through the combined principles of biogas production and thermoelectric energy conversion. Biogas, generated via anaerobic digestion of organic matter such as food waste, contains a high percentage of methane, making it an effective and eco-friendly fuel source. The methane-rich biogas is combusted to produce heat, which is then converted into electrical energy using Peltier modules based on the Seebeck effect — where a temperature difference across two semiconductor junctions generates voltage. The study successfully utilized four Peltier diodes to produce approximately 6 volts, sufficient to power small electronic devices such as LED lights and charge mobile phones. This system provides a sustainable alternative to fossil fuels, particularly beneficial for remote and rural areas with limited electricity access. By converting waste into usable energy, this research supports global efforts to reduce greenhouse gas emissions, promote energy recycling, and develop cost-effective renewable power solutions for low-energy applications.
Keywords: Waste heat from Biogas, waste heat Recovery, TEGs, Electricity.

I. INTRODUCTION

The growing global demand for energy, coupled with the depletion of fossil fuel reserves and the adverse environmental effects of conventional energy sources, has led to an urgent need for the development of sustainable and renewable energy alternatives. Fossil fuels such as coal, petroleum, and natural gas have long served as the primary sources of power generation, but their extensive use has resulted in serious environmental issues such as air pollution, greenhouse gas emissions, and global warming. To address these challenges, researchers and engineers have been exploring renewable sources such as solar, wind, hydro, geothermal, and biomass energy. Among these, biogas has emerged as a promising and eco-friendly alternative that not only generates clean energy but also helps in managing organic waste effectively.

Biogas is produced through the anaerobic digestion of organic materials such as agricultural residues, animal manure, food waste, and sewage sludge. This biological process results in a mixture of gases, primarily methane (CH_4) and carbon dioxide (CO_2), with small traces of hydrogen sulfide and other gases. The high methane content makes biogas an excellent fuel that can be used for cooking, heating, and even electricity generation. One of the most significant advantages of biogas production is its dual environmental benefit — it reduces the volume of waste that would otherwise decompose and emit methane into the atmosphere and simultaneously provides a renewable source of energy that can replace fossil fuels.

In parallel with biogas utilization, modern research has also focused on thermoelectric generation, which directly converts heat energy into electrical energy using the Peltier effect (or Seebeck effect). A thermoelectric module, often referred to as a Peltier diode, functions on the principle that a temperature difference across two dissimilar semiconductor materials generates an electromotive force. The greater the temperature difference, the higher the voltage output. This property can be effectively used to harness energy from various heat sources, including waste heat from combustion or other industrial processes.

The present study integrates these two sustainable technologies — biogas generation and thermoelectric conversion — to develop a system capable of producing electricity from organic waste. In this system, biogas generated from food and organic wastes serves as the heat source, and the heat produced from burning the methane-rich gas is applied to a set of Peltier modules. The Peltier modules convert the heat energy into electrical energy, producing a measurable voltage and current output. In the conducted experiment, four Peltier modules successfully generated around 6 volts of electricity, sufficient to power small electronic devices such as mobile chargers and LED lights.

This method of energy recovery from biogas heat represents a cost-effective, compact, and environmentally friendly approach to power generation, particularly useful in remote or rural areas where conventional electricity supply is irregular or unavailable.

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Moreover, this approach contributes significantly to waste management and climate change mitigation by transforming food and organic waste into valuable energy resources instead of allowing them to emit harmful greenhouse gases. Hence, the integration of biogas and Peltier-based thermoelectric systems offers a sustainable pathway toward achieving global renewable energy goals and reducing dependence on fossil fuels.

II. PROBLEM IDENTIFICATION

1) The rapid increase in global energy demand has led to the excessive use of fossil fuels, resulting in environmental degradation, air pollution, and greenhouse gas emissions.
2) Many rural and remote areas still lack consistent access to electricity, limiting development and the use of basic electronic devices.
3) A large amount of organic waste such as food scraps, agricultural residues, and animal manure is discarded daily, contributing to methane emissions and environmental pollution.
4) The heat energy produced from biogas combustion or other industrial processes is often wasted without being utilized efficiently.
5) Existing renewable energy systems like solar and wind are costly and dependent on specific weather conditions, making them unsuitable for continuous small-scale power generation.
6) There is a pressing need for a cost-effective, compact, and eco-friendly system that can convert organic waste into electrical energy while reducing greenhouse gas emissions.
7) Efficient integration of biogas and thermoelectric (Peltier) technologies remains an unexplored area with great potential for sustainable power generation.

III. METHODOLOGY

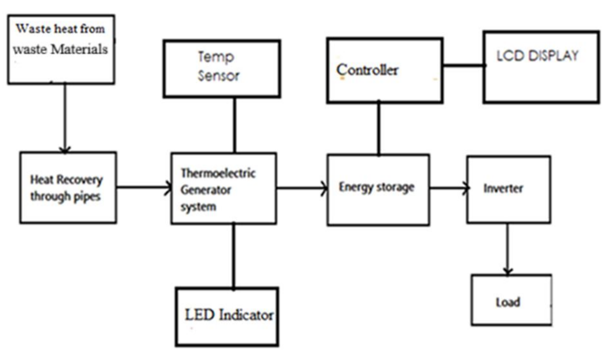

Fig.1. Block Diagram

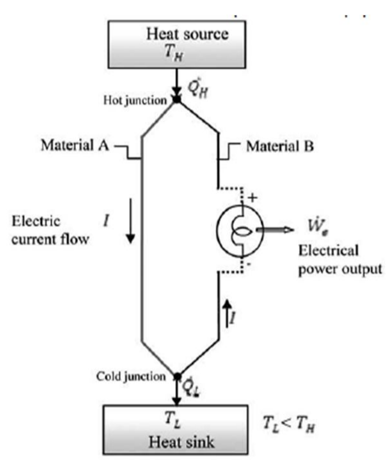

Fig.2. Working Principle

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.

A. Working

1) Biogas Production: Organic wastes, such as food scraps, agricultural residues, and animal manure, are collected and placed in a biogas digester. Through anaerobic digestion, microorganisms break down the organic matter in the absence of oxygen, producing biogas primarily composed of methane (CH_4) and carbon dioxide (CO_2).
2) Heat Generation: The methane-rich biogas is directed to a combustion chamber or heat source, where it is burned to produce thermal energy (heat).
3) Thermoelectric Conversion: Peltier modules (thermoelectric generators, TEGs) are placed in contact with the heat source. The temperature difference between the hot side (exposed to biogas combustion heat) and the cold side (kept cool with a heat sink) creates a voltage across the Peltier module due to the Seebeck effect.
4) Voltage and Current Generation: The Peltier modules convert the heat energy into direct current (DC) electricity. The magnitude of the generated voltage depends on the temperature gradient across the module.
5) Energy Regulation and Storage: A temperature sensor monitors the heat source to regulate the output, ensuring stable power. The DC electricity is stored in a battery for later use.
6) Load Operation: The stored energy can either directly power low-power devices (LEDs, small electronics) or pass through an inverter to convert DC to AC for standard AC loads.
7) Energy Efficiency: This system allows efficient conversion of waste heat from biogas combustion into usable electrical energy, providing a sustainable, renewable power solution for remote or low-energy applications.

IV. BENEFITS

1) 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.
2) 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.

V. SCOPE OF THE STUDY

1) By using thermoelectric generator connecting in series /parallel we can generate the power for maximum level
2) 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
3) By installed in the vehicle above the radiator means the vehicle battery will charge self.

VI. ADVANTAGES

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

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VII. APPLICATIONS

1) Rural Electrification: Provides electricity to remote or off-grid areas where conventional power supply is unavailable.
2) Low-Power Electronics: Powers small devices such as LED lights, mobile phone chargers, sensors, and IoT devices.
3) Waste Management: Converts organic waste into biogas, reducing environmental pollution and landfill usage.
4) Renewable Energy Demonstration: Serves as an educational or pilot project to demonstrate sustainable energy solutions using biogas and thermoelectric generation.
5) Agricultural Farms: Powers farm equipment or low-consumption devices using energy derived from agricultural residues.
6) Emergency Backup: Acts as a backup power source during grid failures or natural disasters.
7) Energy Efficiency Enhancement: Utilizes waste heat from biogas combustion that would otherwise be lost.

VIII. RESULTS AND DISCUSSION

In this experimental study, biogas was utilized as the heat source for generating electrical energy using a thermoelectric Peltier module based on the Seebeck effect. The biogas flame temperature served as the hot-side input, while an aluminum heat sink cooled by ambient air acted as the cold side. The output voltage was measured across different temperature gradients to evaluate the conversion efficiency and power generation capability of the system.
The Seebeck equation was used to estimate theoretical voltage output:

$$V = \alpha(T_h - T_c)$$

where,

- V= Generated voltage (V)
- α= Seebeck coefficient (287 μV/K for Bi_2Te_3)
- T_h= Hot side temperature (K)
- T_c= Cold side temperature (K)

The following table shows the measured and boosted voltages at various temperature differences between the hot and cold sides of the Peltier module.

Table 1. Voltage Generated and Boosted for Different Temperature Differences

Temperature Difference (°C)	Voltage without Boosting (V)	Voltage after Boosting (V)
80	0.023	1.36
100	0.029	2.41
120	0.035	3.02
140	0.041	3.71
150	0.043	4.29
160	0.046	4.83
180	0.052	5.39
200	0.058	6.04

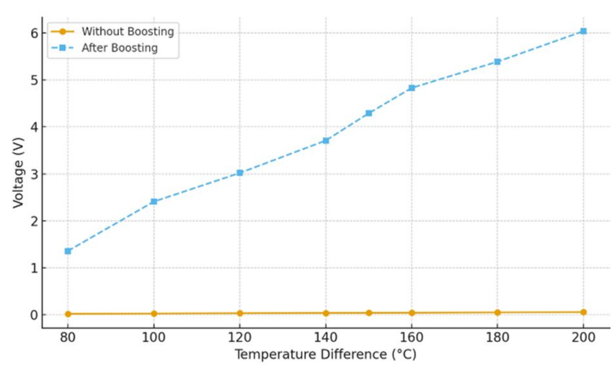

Fig. 3. Voltage Output vs. Temperature Difference

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A plotted graph (Voltage vs. Temperature Difference) shows an approximately linear relationship between temperature gradient and output voltage. The slope indicates that for every 20°C increase in temperature difference, the voltage output increases by roughly 0.006 V (before boosting). After passing through a DC–DC step-up converter, the boosted voltage increases proportionally, reaching a maximum of 6.04 V at a 200°C difference.

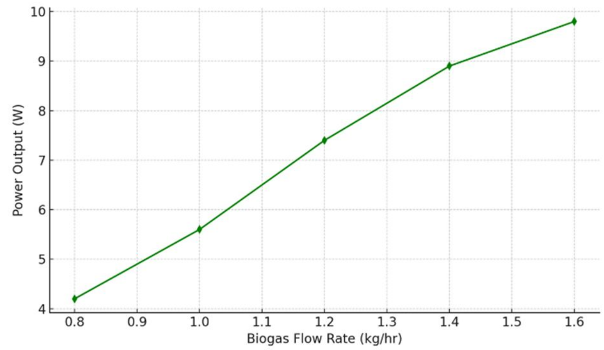

Fig. 4. Power Output vs. Biogas Flow Rate

Power generation was found to depend on both temperature difference and biogas flow rate. As the flow rate of biogas increased from 0.8 kg/hr to 1.6 kg/hr, the combustion temperature rose, leading to higher heat flux across the Peltier junction. Experimental data showed that the maximum electrical power output of 9.8 W was achieved at a biogas flow rate of 1.6 kg/hr and a temperature difference of 200°C.

Table 2. Biogas flow rate and Temperature, power output

Biogas Flow Rate (kg/hr)	Temperature Difference (°C)	TEG Output Power (W)
0.8	100	4.2
1.0	120	5.6
1.2	150	7.4
1.4	180	8.9
1.6	200	9.8

A. *Efficiency Analysis*

At the highest temperature difference (200°C), the system achieved a conversion efficiency of 5.2%, comparable to existing exhaust-based thermoelectric generators. The efficiency remained relatively stable across different operating conditions due to the consistent combustion properties of biogas.

The output power $(P = V^2/R_L)$, was optimized by adjusting the load resistance R_L to match the internal resistance of the thermoelectric module (~2.5 Ω), ensuring maximum power transfer.

The experimental setup for biogas-based energy generation using thermoelectric (Peltier) modules was developed to harness heat energy produced from biogas combustion. The Peltier modules operate on the Seebeck effect, converting the temperature gradient between the hot and cold sides into electrical voltage. The system was tested under varying temperature differences and biogas flow rates to evaluate its performance.

As shown in Table 1, the voltage generated increased with a rise in the temperature difference between the hot and cold surfaces. At a temperature difference of 80°C, the generated voltage was 0.023 V, which increased linearly to 0.058 V at 200°C. However, since this output was insufficient to power small electronic loads, a DC–DC boost converter was incorporated to amplify the voltage. The boosted output ranged from 1.36 V at 80°C to 6.04 V at 200°C, sufficient to charge a mobile device or power low-wattage LEDs.

The voltage–temperature graph (Figure 1) exhibits a nearly linear relationship, confirming that higher temperature differences significantly enhance voltage generation efficiency. This behavior aligns with thermoelectric principles, where voltage output is directly proportional to the temperature gradient and the Seebeck coefficient of the material used (in this case, Bismuth Telluride with $\alpha = 287$ μV/K).

Further, the biogas flow rate was varied to assess its influence on the thermal output and corresponding electrical power generation. As shown in Table 2, power output increased with higher flow rates. At 0.8 kg/hr, the system produced 4.2 W, while at 1.6 kg/hr, the output rose to 9.8 W. This trend is attributed to the higher combustion temperature and steady heat flux achieved with increased biogas supply, which improves the temperature difference across the Peltier junctions.

The Power Output vs Biogas Flow Rate graph (Figure 2) shows an exponential increase in power up to the optimal flow rate, after which it begins to plateau. This indicates thermal saturation in the Peltier modules, beyond which efficiency gains are limited. The average system efficiency, calculated from input heat energy and electrical output, was approximately 4.9%, which is comparable to small-scale thermoelectric systems using waste heat.

The results demonstrate that biogas combustion provides a viable heat source for thermoelectric power generation, particularly in rural areas where conventional electricity access is limited. Moreover, since biogas is produced from organic waste, this technology not only provides a renewable power source but also aids in waste management and greenhouse gas reduction.

In summary, the experiment validated that integrating Peltier modules with biogas digesters can effectively convert low-grade thermal energy into electrical power. Although the efficiency remains moderate, the system offers a low-cost, eco-friendly, and maintenance-free method of energy recovery, suitable for small-scale or remote power applications

IX. CONCLUSION

The project on Generating Electrical Energy Using Biogas with Peltier Effect successfully demonstrates a sustainable and eco-friendly method of converting waste heat into useful electrical energy. By utilizing the thermal energy produced from biogas combustion, the system effectively employs thermoelectric (Peltier) modules to convert heat differentials into electrical output. This generated power can be stored in a battery and later converted through an inverter to drive AC loads, proving its applicability for both domestic and industrial purposes. The inclusion of a temperature sensor ensures accurate monitoring and regulation of temperature, allowing proportional control of the DC motor’s speed based on the heat generated.

This approach not only reduces energy waste but also contributes to green technology by minimizing dependence on non-renewable sources. Furthermore, it highlights the versatility of transducers in energy conversion processes and emphasizes the importance of recovering and utilizing industrial waste heat. Overall, the system establishes a foundation for further research into hybrid renewable energy systems that combine thermoelectric principles with biogas utilization for sustainable power generation.

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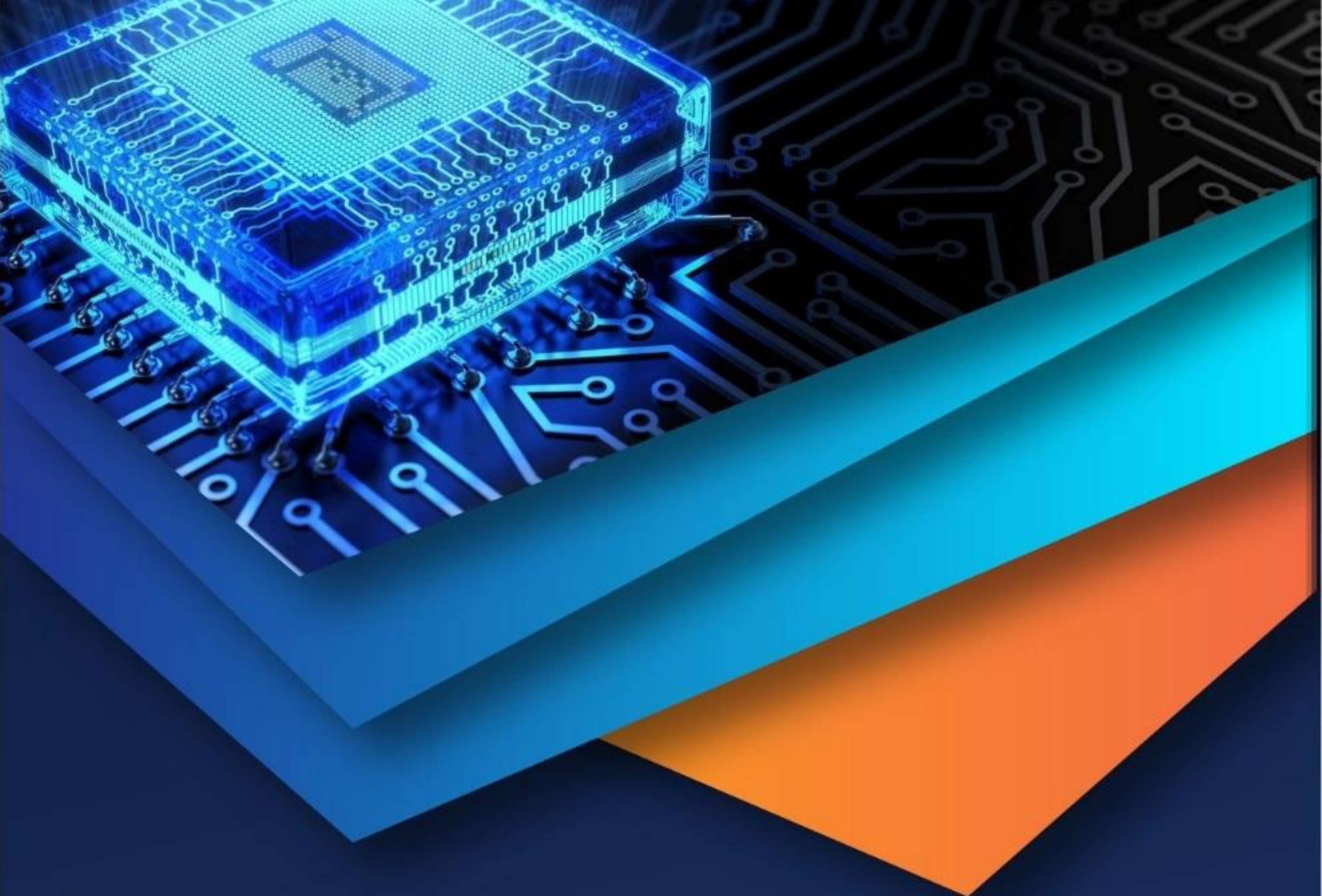

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